SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

1957 Literature Review, Part I—Research Committee
Analytical Methods, Sewage

Refinery Wastes—Ludzack et al.

Coliform Reduction by Halogens—Connell et al.

Economics of Pollution Control—Renshaw

FSIWA M.O.P. No. 6—Units of Expression

1957 Operators' Forum
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MAY 1958—VOL. 30, No. 5

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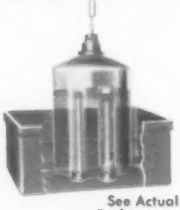

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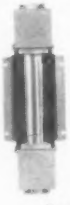

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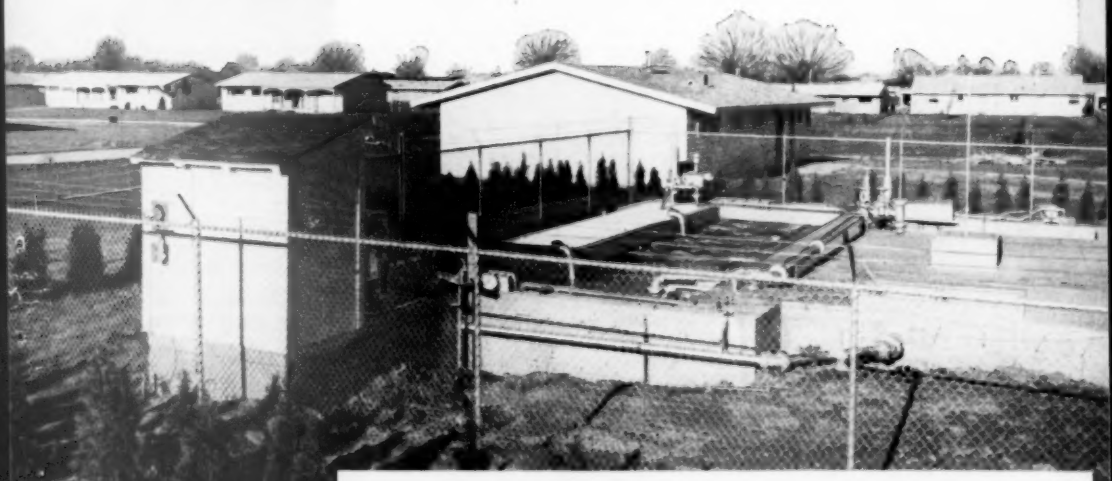

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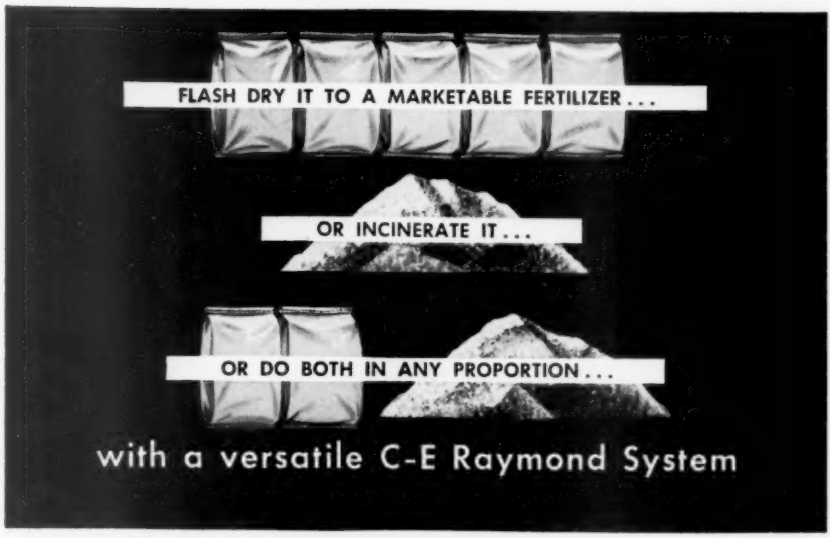

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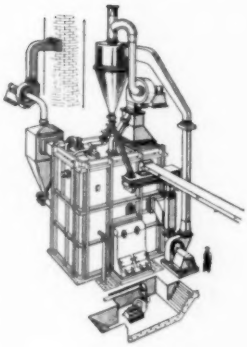

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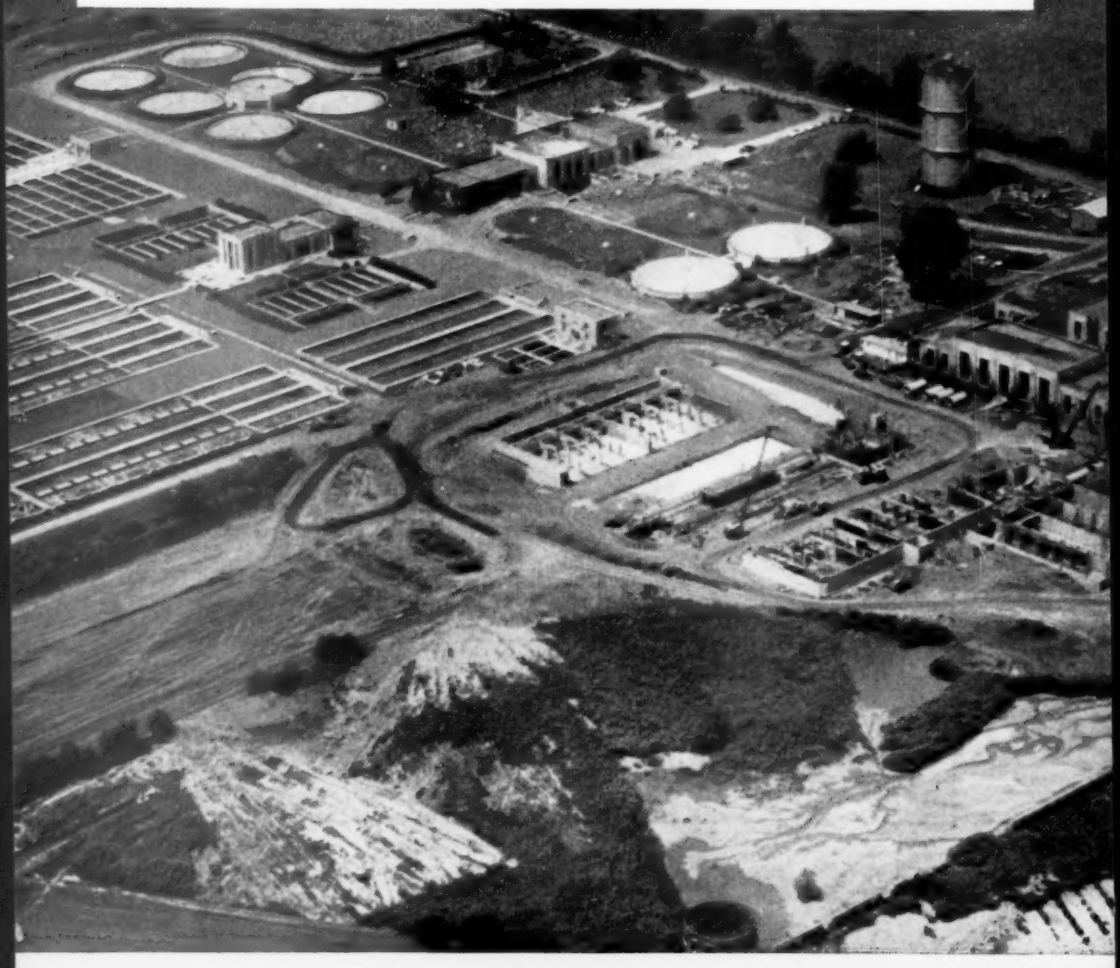

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Association	*Place*	*Time*
Central States Sewage and Industrial Wastes Assn.	Purdue Univ. Lafayette, Ind.	May 5–7, 1958
Arizona Sewage and Water Works Assn.	El Conquistador Hotel Tucson, Ariz.	May 15–17, 1958
Sweden (Foreningen for Vattenhygien)	Consert Hall Oerebro, Sweden	May 16–17, 1958
New York Sewage and Industrial Wastes Assn.	Grossinger Hotel Catskills, N. Y.	May 26–27, 1958
Alabama Water and Sewage Assn.	Alabama Poly. Inst. Auburn, Ala.	June 4–6, 1958 (*Revised Date*)
New England Sewage and Industrial Wastes Assn.	Colonial Hotel Gardner, Mass.	June 4–5, 1958
Maryland-Delaware Water and Sewage Assn.	Francis Scott Key Hotel Frederick, Md.	June 12–13, 1958
Ohio Sewage and Industrial Wastes Treatment Conf.	Commodore Perry Hotel Toledo, Ohio	June 18–20, 1958
Iowa Sewage and Industrial Wastes Assn.	Hotel Chieftan Council Bluffs, Iowa	June 18–20, 1958
Michigan Sewage and Industrial Wastes Assn.	Charlevoix Hotel Charlevoix, Mich.	June 23–25, 1958
Institute of Sewage Purification	Floral Hall Southport, England	June 24–27, 1958
Pennsylvania Sewage and Industrial Wastes Assn.	Penn. State Univ. University Park, Pa.	Aug. 13–15, 1958

THIRTY-FIRST ANNUAL MEETING

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Sheraton-Cadillac Hotel, Detroit, Michigan
October 6–9, 1958

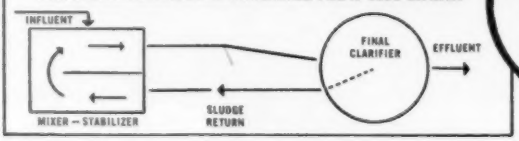
INFILCO *High-Rate* SEWAGE TREATMENT

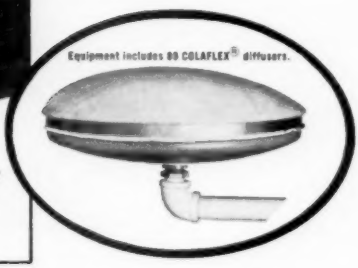
twice as fast in half the space

Sewage plant of Washington County Sewer Improvement District No. 1, at Bartlesville, Okla., is compact and efficient with INFILCO equipment.

Engineering by Wood & Craig Consulting Engineers, Tulsa, Okla.

FLOW DIAGRAM: DESIGN AVERAGE FLOW 0.39 M.G.D.





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Period	Ave. Flow MGD	Average B.O.D. (p.p.m.) Raw Sewage	Final Effluent	% Removal	Suspended Solids (p.p.m.) Raw Sewage	Final Effluent	% Removal
1/14-2/3 '55	0.253	197	18	90.8	225	20	91.0

If your problem involves greater volume in less time from less space—*at lower cost*—consult INFILCO because INFILCO KNOWS HOW to help you solve it. Over 60 years of experience and the most complete and advanced line of equipment are available to you. Write today for full information on the interesting Bartlesville installation and Bulletin No.

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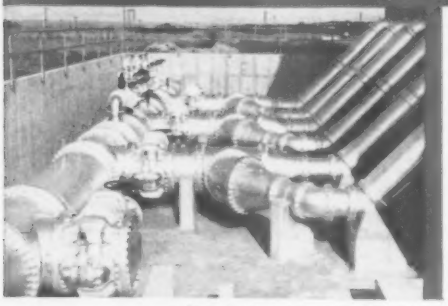

Chicago, Ill.—Cast Iron Pipe for installation of new water main under West Madison Street.

Corpus Christi, Texas—Cast Iron Pipe installation in filtration plant showing 48" discharge manifold which is connected to 48" Cast Iron city supply line.

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LOCATION	SIZE	TEST SECT. IN FEET	VELOCITY F.P.S.	AGE YEARS	W & H "C" FACTOR
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Chicago, Illinois	36"	7,200	2.6-3.6	New	147
New Orleans, La.	12"	39,650	1.3-2.9	New	141
Cordor, Mo.	8"	21,350	0.9-2.3	New	143
Univ. of Illinois	8"	400	3.14	New	150
Concord, New Hamp.	14"	500	1.7-2.2	New	151
Concord, New Hamp.	12"	500	2.0-3.4	11	142
West Palm Beach, Fla.	12"	500	3.6-5.4	15	139.5
Greenville, S. C.	30"	87,376	2.4-2.7	12	148.5
Corpus Christi, Tex.	30"	65,641	1.1-1.8	6	146
Summerville, S. C.	8"	500	1.98-2.43	13	142.5
Champaign, Illinois	16"	3,920	3.1-5.6	22	139.3

*Available upon request: Booklet containing flow test and tables on Cast Iron Pipe.

Here's the proof of strength

1. CRUSHING STRENGTH*. . . Standard 6" Class 150 cast iron pipe will withstand a crushing load, under standard tests, of 17,900 pounds per foot . . . important where heavy fill or shock from heavy traffic loads are encountered.
2. BEAM STRENGTH*. . . Settlement soil movement, or disturbance of the soil by underground construction places a heavy strain on pipe. A length of 6" class 150 cast iron pipe bears up under a load of 20,790 pounds and deflects over 2¼ inches.
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*Based on independent laboratory tests.

pipe FOR MODERN WATER WORKS

Mr. George W. Welsh, Jr. (left), Deputy Chief of Bureau of Operations for Baltimore County, and Louis A. Hauptman, Asst. Superintendent of Pumping Division, inspect Fairbanks-Morse non-clog pumps in Stella Maris Pumping Station.

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Over two-thirds of the pumps in the system are Fairbanks-Morse, driven by F-M motors. Typical of F-M ability to meet exact requirements are the installations of F-M bladeless-impeller pumps, designed for non-clog, trouble-free operation.

Like so many communities today, Baltimore County finds exclusive advantages in working with Fairbanks-Morse—because the broad F-M line provides the ideal combination: the right type, right size pumps driven by the right type, right size diesel engines or electric motors—all backed by undivided F-M responsibility. Why not investigate what F-M unmatched experience and facilities can do for you? Write today to Fairbanks, Morse & Co., Dept. SIW-5, 600 S. Michigan Avenue, Chicago 5, Illinois.

Ask for F-M Bulletin 5410K on Non-Clog Pumps.

FAIRBANKS-MORSE

a name worth remembering when you want the BEST

PUMPS • SCALES • DIESEL LOCOMOTIVES AND ENGINES • ELECTRICAL MACHINERY • RAIL CARS • HOME WATER SERVICE EQUIPMENT • MAGNETOS

MILLION-YEAR-OLD WONDER CHEMICAL HELPS

BERMICO®

Bituminized Fibre Pipe Exceed Federal Specifications SS-P-356

From bituminous coal, formed by Nature millions of years ago, comes *coal tar pitch*—one of the wonder chemicals of today. On all types of outdoor structures, roads, roofs—wherever successful water and corrosion resistance is a *must*—there *coal tar pitch* has proved its lasting effectiveness.

Bermico, the tough cellulose fibre pipe, for house-to-septic tank or sewer connections, is thoroughly impregnated with *coal tar pitch*.

It exceeds Federal Government performance requirements for Water Absorption—Crushing Strength—Chemical and Kerosene Resistance—Hot Water Resistance—Heat Resistance—Resistance to Flattening—Beam Strength.

That's why more and more code authorities throughout the country are including Bermico bituminized fibre pipe in their codes.

Inquire about new full-color movie: "Modern Pipe For Modern Living." Write Dept. JB-5, Brown Company, 150 Causeway St., Boston 14, Mass. (Mills: Berlin, N. H.; Corvallis, Ore.)

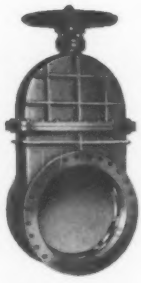
Speed up installation with:
BERMICO®
for house to sewer or septic tank
BERMISEPTIC®
for septic tank disposal fields

Guarantee of Quality BPI

Specify IOWA for every job

Iowa's complete line of valves for treatment plants assures you of efficient operation, low maintenance cost, and replacement parts when needed in years to come.

IOWA CHECK VALVES—Swing gate type for use in either horizontal or vertical pipe lines. Bronze trimmed throughout. Stainless steel hinge pins. Leather or rubber faced gates, or solid bronze, as desired—aluminum gates available for air service.



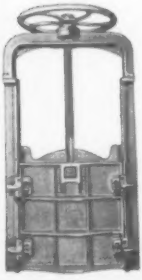
IOWA MEDIUM AND LOW PRESSURE VALVES—either non-rising stem or outside screw and yoke types. Designed as carefully as those conforming to A.W.W.A. specifications but with lighter construction for lower pressures.

Write TODAY for descriptive literature

IOWA FLAP VALVES—all iron; can be furnished with bronze hinge bolts or fully bronze mounted—including bronze bolts, flap ring and seat ring—when required.

CLOW HYDROSTATIC RELIEF VALVES — commonly used in bottom of concrete tanks to prevent ground water from floating the tank. Close-grained cast iron body and lid; lead seat ring and lid ring. Cast iron grate in bottom prevents foreign matter from entering tank.

IOWA PLUG DRAIN VALVES—either rising or non-rising stem type. High strength cast iron bodies; bronze stem, operating nut, disc ring and seat ring; rustproof steel bolts and nuts. Handwheels, extension stems, plain or indicating floor stands if required.



IOWA SLUICE GATES—can be used in lines having both seating and unseating pressures. High strength cast iron, bronze mounted, with solid bronze adjustable wedges. Can be equipped with cylinder or motor unit for automatic operation.

IOWA SHEAR GATES—either all iron or iron, bronze mounted. Gate-seating wedges bolted on, permitting replacement without replacing frame.

For 45 years a reliable source for **precision engineered products**

IOWA VALVE COMPANY

A Subsidiary of James B. Clow & Sons

Oskaloosa, Iowa

GRAVER SYSTEMS SIMPLIFY TREATMENT OF COMPLICATED PLATING WASTES at MARTIN-ORLANDO

Building missiles is a complex job. Thousands of intricate parts must be machined to close tolerances and plated or coated with a wide variety of materials to resist corrosion and guarantee dependable performance during flight. Many are chrome plated, silver plated, anodized, phosphatized, pickled, passivated or processed in other ways. An unusually large number of acid and chemical wastes results, including nitric acid, hydrofluoric acid, sulfuric acid, caustic and cyanide. Handling these wastes is a complex problem in itself.

Martin-Orlando of Florida, builders of guided missiles, selected Graver to supply all units and auxiliary equipment for a treatment plant based on plans and specifications prepared by the Architect-Engineers. Graver, working with the consulting engineers, fabricated and installed a plant which handles this treatment problem simply and directly. Four integrated systems effectively treat all wastes in the spent baths and rinse. The plant is safe, efficient and simple to operate and maintain.

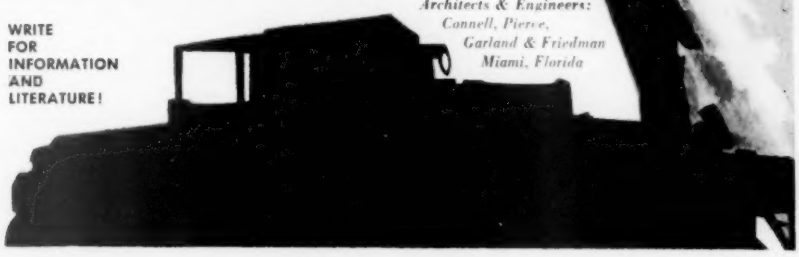
This installation is only one of the many modern plating waste treatment systems Graver has furnished for large and small manufacturers in every field. Graver supplies all types of equipment, from simple units to entire plants and makes available a complete service, including research and development, manufacturing and installation, when required. Whatever *your* waste treatment requirements, Graver has the modern designs, equipment and processes to do the job efficiently . . . economically. Every installation is tailored to specific needs.

GRAVER

Industrial Waste Treatment Dept. W-520
GRAVER WATER CONDITIONING CO.
Division of Union Tank Car Company
216 West 14th Street, New York 11, N. Y.

Architects & Engineers:
Connell, Pierce, Garland & Friedman
Miami, Florida

WRITE FOR INFORMATION AND LITERATURE!



This pipe may have to carry

1978 WATER

at 1958 rates.....

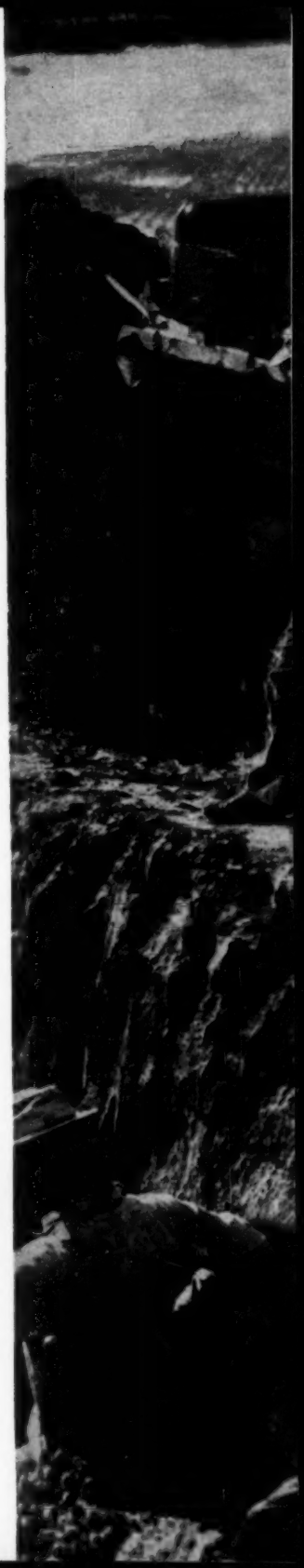
Even today after two decades of rapidly advancing costs, many cities have been forced to operate without rate increases for periods of twenty years or more. What the next twenty years may bring in operating costs no one, of course, knows. It is certain, though, that the water carrying installations using concrete pressure pipe will be in the best position to keep costs at the very minimum.

Concrete pressure pipe has virtually complete freedom from corrosion, and tuberculation. This means not only minimum maintenance costs but also means sustained carrying capacity to keep pumping costs low. Concrete pressure pipe also has the elasticity to resist bursting from surge and water hammer. And no other pipe is easier to install.

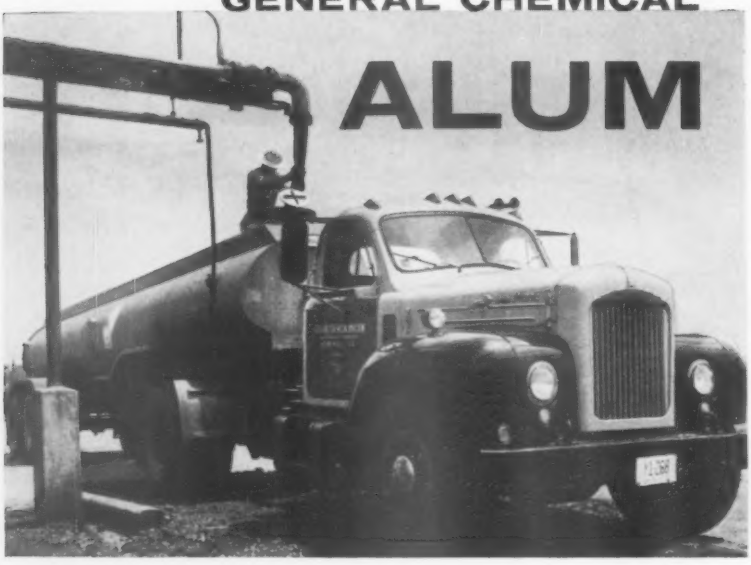
Concrete
PRESSURE
Pipe

WATER FOR GENERATIONS TO COME

AMERICAN CONCRETE PRESSURE PIPE ASSOCIATION
228 North LaSalle Street
Chicago 1, Illinois



GENERAL CHEMICAL ALUM



Where you want it... As one of America's major producers of both dry and liquid aluminum sulfate, General Chemical has strategically located plants from coast to coast—assuring you of dependable, near-by supply almost *anywhere* in the U.S. and Canada.*

As you want it... "GC" Alum has met the most rigid specifications for more than 50 years. In both dry and liquid forms, it is first choice of most industrial and municipal users—who know they can count on General for the uniform high quality they need.

When you want it... General Chemical is geared to supply fast service at *all* times. This can be especially important when emergencies loom.

Add them up! Near-by service and supply . . . quality and dependability . . . speed. You get them all from General Chemical! Call your nearest General Chemical sales office listed below for further information.

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A NEW CONCRETE PRESSURE PIPE

of unequalled **ECONOMY**

Recently, a large chemical company in Louisiana selected Cen-Vi-Ro Concrete Pressure Pipe to move fresh water into its new plant. Cen-Vi-Ro easily exceeded the hydrostatic and other test requirements, insuring the owners a permanent and maintenance-free installation. The close tolerances of Cen-Vi-Ro's precision-formed joints . . . measured in thousandths . . . combined with special O-ring type Rubber Gasket Seal assure perfect leakproof connections under even the most adverse field conditions.

Lower first cost plus longer lengths result in a more economical installation . . . *every time!*

Write for complete Cen-Vi-Ro information . . .

THE NAME, ITSELF, MEANS THE WORLD'S FINEST PIPE!

CEN — VI — RO

CEN comes from CENtrifugally spinning the very dry "earth-moist" mixture, fed into the form by belt conveyor in uniform layers.

VI comes from VIbration of the spinning form during the charging period. Specially designed vibrator-tampers on the underside of the form do this job.

RO comes from ROlling the mixture under great pressure applied by a specially designed steel roller.

"Organized for Service"

Vulcan Materials Company

Vulcan Materials Company
CONCRETE PIPE DIVISION
P. O. DRAWER 155, BIRMINGHAM, ALABAMA
A Division of Vulcan Materials Company

COMPLETE LINE to Meet Your Exact Needs

Including many Exclusive Developments

Utilize our many years of experience in the development and manufacture of municipal and industrial waste treatment equipment. Our staff of engineers is ready to cooperate with consulting and operating engineers in suggesting the process of treatment and type of equipment best suited to individual needs.

BIO-ACTIVATION—exclusive system combines best qualities of trickling filter and activated sludge. *Bulletin 259B.*

MECHANICALLY CLEANED SCREENS AND GRINDER—with intermittent automatic control. *Design data in Technical Supplement MS.*

GRIT CHANNELS—exclusive Camp Chamber design and Regulator permit easy and instant variation in velocity. *Design data in Technical Supplement CR.*

GRIT SETTLERS—with conveyor, elevator, and exclusive Hydrowash unit which removes grease and organic matter from grit. *Bulletin 249B.*

GREASE FLOTATION UNIT—removes grease and oils, produces simultaneous aeration and agitation, and oxidizes objectionable odors. *Bulletin 260B.*

SEWAGE AND SLUDGE PUMPS—horizontal and vertical pumps in wide range of sizes, capacities and heads—including cutting type primary sludge pumps, enclosed impeller type sewage pumps, single vane impeller type sewage pumps and recirculation pumps. **Send for Bulletins.**

SLUDGE COLLECTORS—for rectangular and circular tanks . . . flight type and helicoid cross conveyors . . . sludge valves. *Bulletin 253B and Technical Supplement TV.*

AERATORS—downflow mechanical air diffusion type provides thorough and adjustable oxygenation and circulation of liquor. *Bulletin 265A.*

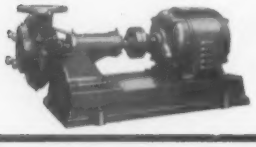
JET AERATION—exclusive method produces an unprecedented rate of oxygen absorption. *Bulletin 265A.*

ROTARY DISTRIBUTORS—reaction and positive drive types with exclusive trouble-free oil seal. *Design data in Technical Supplement RD.*

DOWNFLO FLOCCULATION UNIT—for slow mixing and flocculation of chemicals in sewage treatment processes. *Design data in Technical Supplement PF.*

Send for informative bulletins listed above.

Inquiries on new installations or improvements of existing plants will receive prompt attention.



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110 North Broadway
AURORA, ILLINOIS

Pumping, Sewage Treatment, and Water Purification Equipment
RESEARCH • ENGINEERING • MANUFACTURING

Offices: Chicago • New York • Cleveland • Cincinnati • Kansas City • Sales Representatives throughout the World

Clay Pipe for Underdrains

BECAUSE it "gives the *best* resistance to sanitary sewage," more than nine miles of Vitrified Clay Pipe were specified for Sandusky, Michigan's new sewer system and treatment plant. Clay Channel Pipe underdrains—installed in treatment plant sand filters—will handle the highly-corrosive wastes found in this service for years to come. Because it is the only chemically-inert pipe, Clay Pipe is the only pipe that does not deteriorate from the corrosive action of sewer acids and gases.

When you plan sewer improvements, protect the long-term investment with Vitrified Clay Pipe . . . the only pipe with *all* the features you can trust.

CONSULTING ENGINEERS: Spicer Engineering Company, Saginaw
CONTRACTORS: Taylor Construction Company, Saginaw

C-758-1A

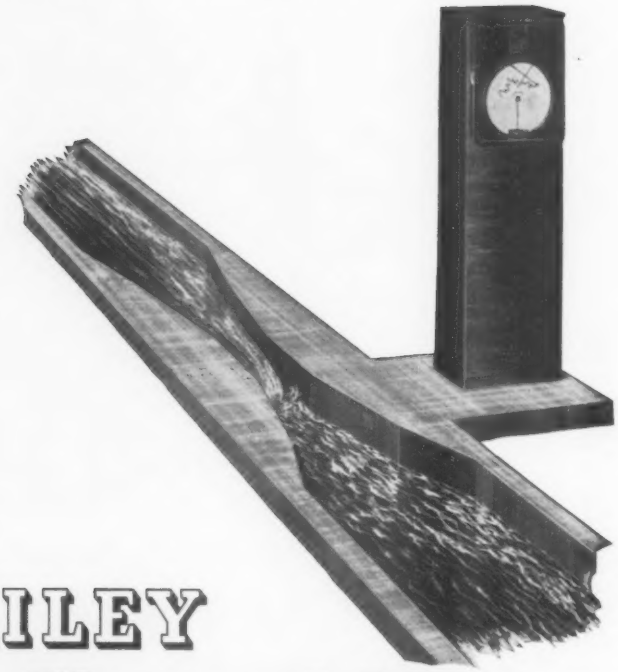
Vitrified **CLAY PIPE** *Never Wears Out*

NATIONAL CLAY PIPE MANUFACTURERS, INC.

1820 N Street, N. W., Washington, 6, D. C.

311 High Long Bldg., 5 E. Long St., Columbus 15, Ohio • 703 Ninth & Hill Bldg., Los Angeles 15, California

Box 172, Barrington, Illinois • 206 Mark Bldg., Atlanta 3, Georgia



BAILEY

Open Channel Meters

for trouble-free low cost measurement of

Sewage, Industrial Wastes, Sludge, Irrigation, Water Supply

Bailey Meters offer these advantages—

1. Easy to Install and Maintain
2. Retain Accuracy
3. Self Cleaning
4. Adjustable Capacities
5. Totalize Multiple Flows
6. Chemical Feed Control
7. Flow and Ratio Controls
8. Low Cost

For further information on how Bailey Meters can meet your needs, ask for Bulletin M22-5.

MU25

Bailey Meter Company

1066 Ivanhoe Road • Cleveland 10, Ohio

Meters and Controls for Sewage and Water

Venturi Tubes • Flumes • Weirs • Nozzles • Orifices • Direct Mechanical and Remotely Located Registers • Air-Operated, Electronic and Electric Controls

COMPLAINTS SOLVED ...with OZENE!

End odors—and the troublesome complaints they cause—quickly, easily, economically by using OZENE, the tested and proved material that controls odors two ways. OZENE's dual action (1) masks existing odors while it (2) attacks the causes of odors—sulphide-forming bacteria and mold microorganisms.

OZENE is currently being successfully used in:

- sewage, leather and rendering plants
- land-fill waste disposal projects
- dried milk, cheese, cannery and other food plants
- industrial lagoons
- new excess-capacity sewers
- drainage ditches
- incinerators
- storm sewers
- sewer breaks
- sludge de-watering
- fish-market areas
- refuse cans and trucks
- kennels, etc.

OZENE is a concentrated material and only small amounts are required for most applications. For odor-controlling sprays, OZENE can be diluted as much as 100-to-1.

Write specifying items desired (no cost):

1. OZENE test samples
2. Data on OZENE for odor control

If you have a special odor control problem, please describe it to receive our recommendation.

SOLVAY

SOLVAY PROCESS DIVISION

Allied Chemical

61 Broadway, New York 6, N. Y.

BRANCH SALES OFFICES

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Get waste treatment off to a safe start...with LINK-BELT screens

...for removal of large solids

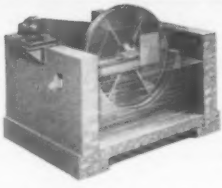
THRU-CLEAN SCREENS. Automatic, chain-operated rakes clean from downstream side, are designed to eliminate jamming by debris. Vertical mounting minimizes friction between rakes and bars.

STRAIGHTLINE SCREENS. Automatic, cable-operated rake cleans from upstream side, assures clean, positive screenings removal. Easily accessible—no moving parts are mounted under water.

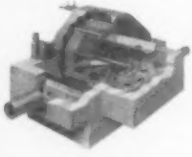
TRITOR SCREENS. Combined screen and grit chamber saves smaller plants the cost of separate units to remove large solids and detritus. Shredder for screenings can be provided, if desired.

...or small

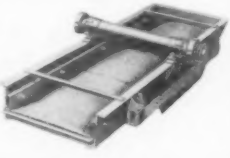
ROTARY DRUM SCREENS. Effectively remove fine solids from large volumes of water. These screens are best suited to installations where a fixed water level can be maintained.



LIQUID VIBRATING SCREENS. For thorough removal of fine solids from industrial liquids. High-energy vibration provides a relatively dry product with minimum blinding or clogging.



REVOLVING DISC SCREENS. For applications similar to rotary drum screens, but where volume is less. Simplified design contributes to ease and economy of installation. Very little maintenance required.



WHERE coarse or fine solids threaten to clog or damage subsequent equipment . . . where stream pollution must be prevented or valuable by-products can be recovered — efficient waste treatment begins with a Link-Belt screen. This broad line is your assurance of an impartial recommendation based on the specific nature of your waste. For full data, contact your nearest Link-Belt office or write for Book 2587.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. To Serve Industry There Are Link-Belt Plants and Sales Offices in All Principal Cities. Export Office, New York 7; Canada, Scarboro (Toronto 13); Australia, Marrickville (Sydney), N.S.W.; South Africa, Springs. Representatives Throughout the World.

14.512

The more difficult your sewage odor or treatment problems the more startling and definite the proof...

"Cloroben is at least twice as effective as other products"

states authoritative Millburn, New Jersey report, appearing in April, 1958 issue of Public Works.

Well worth your attention is the complete Millburn history, typical of the reports sent us by professional sanitation engineers and sewage treatment plant operators.

Located along the Watchung Hills in Union County, Millburn is a fine suburban community. When vile sewage odors began to permeate the area in 1953, the residents demanded relief. During the summer of 1954 CLOROBEN was first introduced into the sewage collection system, and immediately stopped odor complaints. The CLOROBEN treatment was continued through 1954 and 1955 with excellent results. All odors were effectively controlled in lift stations, force mains and low gradient sewer lines.

Then, in 1956, various emulsifiable chlorinated benzenes were offered the township. Advertising claims indicated these products were almost identical to CLOROBEN. In price they compared favorably. So, in 1956 competitive bids were required, specifying CLOROBEN or equal. And, the contract was awarded to the lowest bidder.

Right after the change from CLOROBEN to the cheaper substitute, odor complaints began coming in. The amount of the chlorinated benzene used was doubled, then quadrupled. Everything else possible was done. Low gradient lines were flushed periodically, and lift station wet-wells cleaned weekly. But, the odor complaints persisted and increased. Sulphides and pH determinations were made throughout the system. Odorous areas invariably showed sulphides at 0.3 ppm or more, with pH below 7.5. The situation got even worse right up to July 31, 1957, when use of the cheap chlorobenzene substitute was stopped. On the following day CLOROBEN was reinstated.

Results were startling. By mid-afternoon sulphides had been reduced 50%, pH was back to 7.5. By evening sulphides in lift stations decreased by as much as 80%. And, no further odor complaints have been received since! Concrete and positive proof of the superiority of CLOROBEN in controlling odors and suppressing sulphide formations in sewage!

To effectively control odors and suppress sulphide formation, no product of its kind compares to CLOROBEN in safety, efficiency, and economy. And, only up-sewer treatment with CLOROBEN provides a non-septic, stabilized influent at the treatment plant for efficient operation.

Remember, CLOROBEN is an exclusive formula, the only chemical product of its kind. So, specify CLOROBEN. Not CLOROBEN or equal.

Because CLOROBEN has no equal.

Yours on Request: Authoritative Technical Bulletin, describing CLOROBEN applications in up-sewer treatment, sewage treatment plant, septic tanks, cesspools, chemical toilets, and industrial wastes. Write "CLOROBEN" on postcard or letterhead for your copy, sent you promptly without cost.

CLOROBEN CHEMICAL CORPORATION

115 Jacobus Avenue, South Kearny, New Jersey Subsidiary of Standard Chlorine Chemical Co., Inc.

Now! Transite Sewer variety

Transite's Ring-Tite® Coupling is designed for high-speed assembly . . . presents no problem in joining lengths of varying crushing strengths or diameters.

CLASS 1500—

CLASS 2400—

CLASS 3300—

CLASS 4000—

CLASS 5000—

Transite Sewer Pipe now classed by Standardized Crushing Strengths

Based on A.S.T.M. 3-edge bearing method (strength in lbs. per lineal foot)

Size Inches	Class 1500	Class 2400	Class 3300	Class 4000	Class 5000
6	1500	2400	3300	—	—
8	1500	2400	3300	—	—
10	1500	2400	3300	4000	5000
12	1500	2400	3300	4000	5000
14	—	2400	3300	4000	5000
16	—	2400	3300	4000	5000
18	—	2400	3300	4000	5000
20	—	2400	3300	4000	5000
24	—	2400	3300	4000	5000
30	—	—	3300	4000	5000
36	—	—	—	4000	5000

Pipe is available in a wide of new crushing strengths

Progressive new concept permits greater efficiency in sewer design . . . reduces overall costs through closer matching of crushing strengths to needs!

HERE'S the biggest sewer pipe advance in years! In a revolutionary move, Johns-Manville introduces five new sewer pipe classifications to greatly simplify accurate sewer pipe specification . . . permitting overall cost saving to a degree never before possible.

Through improved manufacturing methods, Johns-Manville brings you Transite Sewer Pipe in a variety of the more widely needed crushing strengths: 1500, 2400, 3300, 4000, and 5000 lbs. . . . in 11 different diameters ranging from 6″ to 36″ *(see chart)*.

Permits greater efficiency in system design. To the engineer, the new Transite crushing strengths mean new ease in achieving greater efficiency in sewer design. For now he can plan pipe layouts as he has always wanted—selecting pipe on the basis of depth of cut, width of trench, type of soil and manner of bedding. The result: far greater overall economy through use of more realistic safety factors . . . reduction in the need for overdesign . . . with costly concrete encasement and cradling needed in fewer areas.

Let us send you TR-94A, Sewer Design Flow Chart and DS-366, Transite Specifications. Write Johns-Manville, SI, Box 14, New York 16, New York. In Canada, Port Credit, Ontario.

JOHNS-MANVILLE

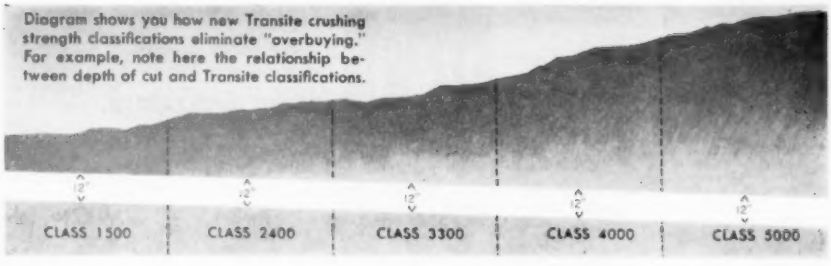
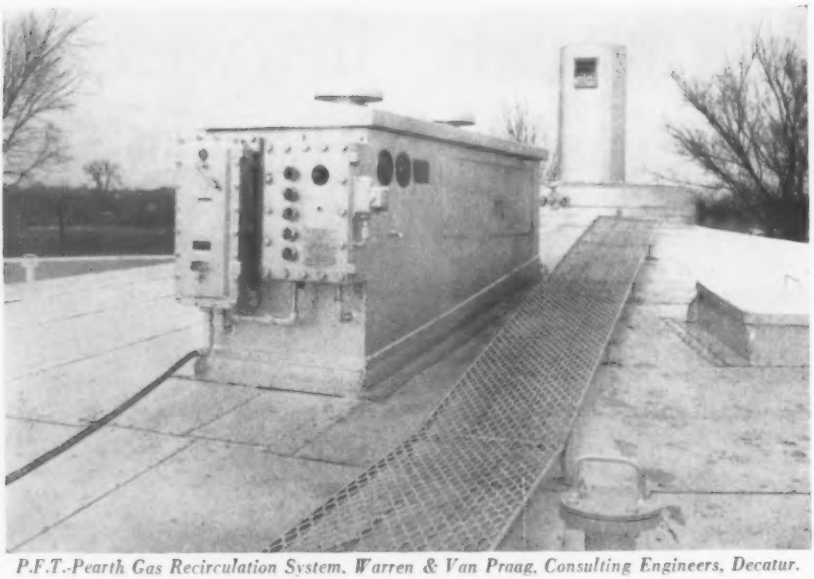


Diagram shows you how new Transite crushing strength classifications eliminate "overbuying." For example, note here the relationship between depth of cut and Transite classifications.
CLASS 1500
CLASS 2400
CLASS 3300
CLASS 4000
CLASS 5000

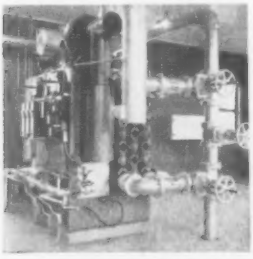


P.F.T.-Pearth Gas Recirculation System. Warren & Van Praag, Consulting Engineers, Decatur.

Decatur, Illinois installs complete modern P.F.T. "Controlled Digestion" system

Unusual industrial and population growth has called for the modernization and expansion of Decatur's sewage treatment plant three times in recent years. Each time Decatur has selected P.F.T. equipment.

The P.F.T. equipment furnished for the most recent expansion is a new digestion system which includes: a 70′ P.F.T. Floating Cover with prefabricated aluminum roofing; the P.F.T.-Pearth gas recirculation system and Model 750 Digestion Heater and Heat Exchanger shown; plus a complete new system of gas piping with P.F.T. gas safety equipment.



Decatur's new P.F.T. No. 750 Gas Fired Heater and Heat Exchanger, with accessory group B controls, provides full automatic digester temperature control.

The P.F.T.-Pearth gas recirculation system includes a gas compressor rated to deliver 150 cfm at 10 psi powered with a 10 hp motor. Controls are provided to automatically discharge to each of 4 peripheral discharge wells in sequence.

P.F.T.-Pearth gas recirculation provides the most effective means of controlling scum formations. This allows the use of the full Digester capacity. Combined with close temperature control with a P.F.T. Heater, rapid and complete digestion is assured. Decatur's new "controlled digestion" system is now geared to meet the needs of this fast growing community.

P.F.T.

waste treatment equipment exclusively since 1893

PACIFIC FLUSH TANK CO.

4241 Ravenswood Avenue
Chicago 13, Illinois

PORT CHESTER, N. Y. • SAN MATEO, CALIF. • CHARLOTTE, N. C. • JACKSONVILLE • DENVER

SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 30 **May 1958** **Number 5**

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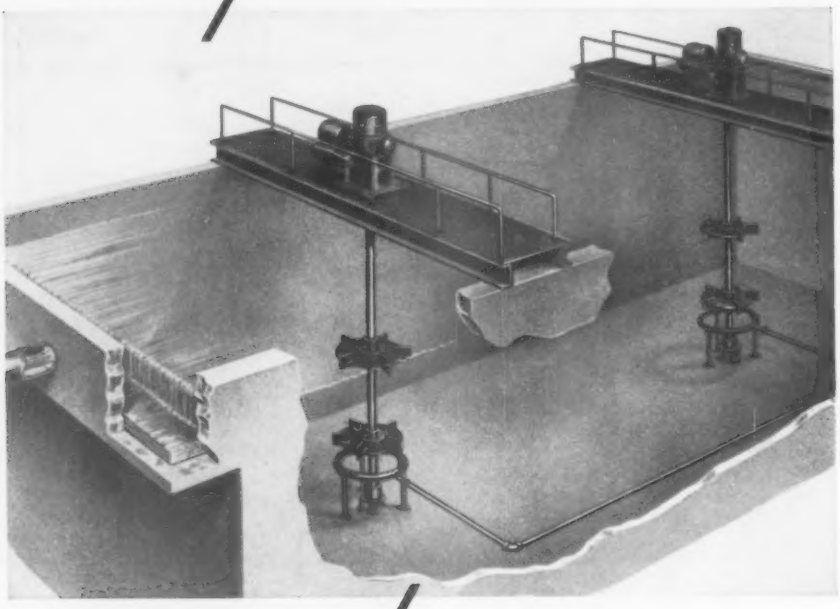

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1957 Literature Review

A REVIEW OF THE LITERATURE OF 1957 ON SEWAGE, WASTE TREATMENT, AND WATER POLLUTION

By H. Heukelekian, *Chairman*, R. Manganelli, *Vice-Chairman*, H. Amberg, E. J. Berg, R. A. Canham, C. H. Connell, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. deS. Furman, I. Gellman, A. E. Griffin, H. G. Harding, R. D. Hoak, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, L. J. McCabe, P. H. McGauhey, W. A. Moore, P. K. Mueller, R. Porges, E. R. Roth, R. C. Specht, A. J. Steffen, C. Straub, C. M. Tarzwell, G. H. Teletzke, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, and R. L. Woodward.

Committee on Research, Federation of Sewage and Industrial Wastes Associations

This section of the Literature Review covers analytical methods and sewage. It will be followed by two other sections dealing with industrial wastes (including radioactivity) and water pollution. These will be published in the June and July issues of This Journal.

Analytical Methods

Biochemical Oxygen Demand

The literature pertaining to the determination of BOD appearing in the past year was sparse.

Bouquiaux and Beaujean (4) report a study made by three cooperating laboratories on the analysis of a large number of river water samples. It was found that considerable variations in results were obtained, depending upon the density of the bacterial population present. Tests made on the same samples in the field and after storage for several days at 4° and 20° C in the laboratory also showed considerable variation. The decrease in BOD after three days of storage varied between 10 and 30 per cent.

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Beaujean, P., "The Consumption of Dissolved Oxygen a Legal Test of Water." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **65**, 192 (1956); *Pub. Health Eng. Abs.*, **37**, 1, 18 (1957).

Herman, A., "Graphic Determination of BOD." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **71**, 414 (1956); *Pub. Health Eng. Abs.*, **37**, 10, 20 (1957).

Okura, T., "Determination of Biochemical Oxygen Demand." *Bunsaki Kagaku* (Japan), **5**, 169 (1956); *Chem. Abs.*, **51**, 9983 (1957).

van Beneden, G., "Role of Seeding in the Measurement of BOD and the Influence of Carbohydrates and Associated Flora on the Values of BOD." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **70**, 363 (1956); *Pub. Health Eng. Abs.*, **37**, 10, 20 (1957).

Chemical Oxygen Demand

Possibly due to failure of the BOD test to measure the pollutional strength of certain waste waters, interest still continues to be manifested in the chemical oxygen demand test.

Rabinowitz (22) described an all-glass apparatus for the wet oxidation of organic compounds. It is claimed that this apparatus makes it possible to obtain a high purity $BaCO_3$ and avoid transfer of sample from the preparation tubes, and also aid in the determination of the amount of $BaCO_3$ formed by use of pre-weighed centrifuge tubes.

Kleinert and Wineor (13) examined the existing methods for the determination of COD of polluted waters. The method selected depends upon the wet-ashing of the sample with H_2SO_4 saturated with KI. After dilution of the sample to about 350 ml it is boiled for several minutes to expel free iodine. The excess KI is then determined.

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Chen, S. L., and Lawer, F. J. H., "Carbon Determination in Biological Material With a Persulfate Oxidation Method." *Anal. Chem.*, **29**, 1225 (1957).

Okada, S., and Uesugi, K., "Chemical Oxygen Demand of Polluted Water." *Himeji Kogo Daigaku Kenkyn Hokoku*, **7**, 74 (1957); *Chem. Abs.*, **51**, 18406 (1957).

Smith, F. G., "Wet Oxidation of Organic Matter Employing Perchloric Acid at Graded Oxidation Potentials and Controlled Temperatures." *Anal. Chim. Acta*, **17**, 2, 175 (1957).

Dissolved Oxygen

Okamoto *et al.* (20) modified Levine's polarographic method (*Anal. Chem.*, **26**, 1297 (1954)) by substituting a rotating platinum electrode (600 rpm). They found that the current at 0.6 v was proportional to the concentration of dissolved oxygen and that no interference resulted from the presence of nitrites. In the presence of organic material, the current is remeasured following the removal of dissolved oxygen with nitrogen and the concentration of oxygen calculated from the difference in the current readings.

Todt (29) used gold-amalgam electrodes having a surface area of 0.1 sq cm for the measurement of the dissolved oxygen content of moving waters. He found that the response time was 15 sec and that the results were not affected by the presence of HCO_3^- and only slightly by HCl or H_2SO_4 at high concentrations. If the electrodes were washed with acetic acid the readings obtained were constant within 5 per cent providing the rate of flow was about 2 ml/sec. The apparatus was used to measure the dissolved oxygen content of the Lippe River and gave results with $\pm$ 10 per cent in the temperature range of 8 to 19°C and a NaCl concentration between 0.3 and 1.1 g/l.

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Levine, H. S., and Kleinschmidt, R. S., "Principles and Problems in Development of a Dissolved Oxygen Analyzer." THIS JOURNAL, **29**, 8, 856 (Aug. 1957).

Potter, E. C., "Microdetermination of Dissolved Oxygen in Water. I–IV." *Jour. Appl. Chem.* (Brit.), **7**, 285 (1957); *Chem. Abs.*, **51**, 15843 (1957).

Vulfson, V. I., and Alekseeva, M. D., "The Application of the Permanganate Method for the Determination of Oxygen Which is Dissolved in Water." *Gidrokhim. Materialy, Akad. Nauk*, **26**, 226 (1957); *Chem. Abs.*, **51**, 17031 (1957).

Nitrogen Compounds

In the determination of ammonia, Lear and Mellon (15) used the well known pyridine-pyrazolone reaction. The variables studied included the minimum concentrations necessary, the

effect of substituted pyridines, and the use of compounds other than pyrazolone. The actual mechanism of the reaction was not determined but it was found to be applicable to low concentrations of ammonia. Another approach to the determination of ammonia was made by Riley and Sinhaseni (24) when they used a microdiffusion method for the separation of ammonia from sea water. They found that the diffusion was approximately 75 per cent complete after 24 hr at 70° C. The recovered ammonia was determined by a modification of the phenate-hypochlorite method. The reduction of NO_3 and NO_2 to NH_3 was carried out by using Raney Ni in the presence of ethylenediamine-tetraacetic acid.

The determination of total nitrogen in waste samples has interested many workers in the field of sanitary chemistry. The results of these studies have at last begun to narrow the variables concerned. Morgan *et al.* (19) adapted the method of Wallace and McKenzie (*Australian Jour. Chem.*, **7**, 55 (1954)) to the field of industrial waste waters using macro instead of micromethods. Using a mixture of amino compounds as a standard, they were able to recover about 98 per cent of the organic nitrogen present when a mercuric sulfate catalyst was used. With this catalyst 7 per cent higher recoveries were possible than with the copper oxide catalyst. Bradstreet (5) studied the ratios of H_2SO_4 to Na_2SO_4 and K_2SO_4 necessary for Kjeldahl digestion. He found that a loss of nitrogen occurred as the digest approached a solid state and that Na_2SO_4 required a higher ratio, thus making this salt unsuitable when refractory compounds were present.

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Isalva, A. B., "Determination of Nitrates in Sea Water Using Diphenylamine and Photoelectric Colorimetry." *Trudy Inst. Okeanol., Akad. Nauk* (S.S.R.), **19**, 304 (1956); *Chem. Abs.*, **51**, 11175 (1957).

Kirsten, W. J., "Dumas Microdetermination of Nitrogen." *Anal. Chem.*, **29**, 1984 (1957).

Simonova, L. K., "Determination of Nitrogen in Complex Compounds." *Zhur. Priklad. Khim.*, **30**, 160 (1957); *Chem. Abs.*, **51**, 9410 (1957).

Steensma, F. A., "Detection of Nitrites and Nitrates, Alone or Combined in Very Dilute Solutions." *Chem. Weekblad* (Netherlands), **53**, 110 (1957).

Sulfur Compounds

Adequate methods are badly needed for the determination of sulfur compounds in sewage and industrial wastes. This is especially true for free sulfur, sulfides, and mercaptans. Ryce and Bryce (25) used a gas partition chromatographic method for the differentiation of H_2S, various mercaptans, and dimethyl and diethyl sulfides. These authors outlined a procedure for the determination of the sensitivity of the method in the presence of air and discussed the relationship between the retention volume, polarity of the liquid column, and the polarizability of the gases being analyzed.

In the analysis of oil refinery wastes, Bertolacini and Barney (3) determined sulfates in concentrations of 2 to 400 ppm by reacting them with Ba chloroanilate in an acid solution. The amount of the acid-chloroanilate formed is proportional to the sulfate content and its absorbance was measured at 530 mμ. They found the method to have a standard deviation of 1 per cent. Those cations which form insoluble chloroanilates are first separated by cation exchange. Concentrations of 100 ppm of Cl^-, NO_3^-, HCO_3^-, and PO_4^{-3} do not interfere.

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Joshi, M. K., "Volumetric Iodate Method for the Determination of CNS^-." *Anal Chim. Acta*, **17**, 288 (1957).

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Sorbo, B. H., "Colorimetric Method for the Determination of Thiosulfate." *Biochim. et Biophys. Acta*, **23**, 412 (1957); *Chem. Abs.*, **51**, 6435 (1957).

Halogen Compounds

Due to conflicting statements in various tests Belcher *et al.* (2) re-examined Mohr's method for the determination of chlorides. They found that the indicator should be neutralized in order to give better pH control at the end point. They also found that the interference due to phosphate and arsenate was less serious than usually considered and that fluoride caused no interference. In case Fe is present, its effect could be partially masked with F. Aluminum gave slightly higher results while Zn gave no interference. The use of EDTA was unsuccessful.

Megregian (17) found that the current generated by the Zr-Pt cell was proportional to the F concentration between 2.5 and 20 mg/l. The determination is simple, requiring only 5 to 30 min. It was also found that a Zr electrode can be used as an indicating electrode in titrating the zirconyl ion with F^-. This electrode gives a sharp rise in potential when as little as 2.5 mg of F^- is present. Brownley and Sellers (6) used an ascorbic acid-Ti (IV) complex for the determination of fluoride. The authors claim it to be as accurate as any of the methods in use today. It also has the advantage of short color development time and the reagents are easily available.

Palin (21) in the determination of free and combined chlorine substituted diethyl-p-phenylenediamine for the dimethyl compound. The diethyl compound is claimed to give a sharper end point and the indicator solution is more stable. In the original article interferences are discussed, as well as giving colorimetric and volumetric procedures for the determination of both types of chlorine.

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Kraljic, I., and Mate, M., "Photometric Determination of Micro Amounts of Cyanides." *Croat, Chem. Acta* (Yugoslavia), **28**, 249 (1956); *Anal. Abs.*, **5**, 8, 2541 (1957).

Kul'berg, L. M., and Berzova, L. D., "New Method for the Specific Determination of Chlorine." *Zhur. Anal. Khim.* (U.S.S.R.), **11**, 470 (1956); *Anal. Abs.*, **4**, 5, 1537 (1957).

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Murtz, G. V., Viswanathan, T. S., and Ramakrishna, U., "Estimation of Fluorine in Microgram Quantities." *Anal. Chim. Acta*, **16**, 215 (1957).

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West, P. W., and Coll, H., "Direct Spectrophotometric Determination of Chloride Ion in Water." *Jour. Amer. Water Works Assn.*, **40**, N-485 (1957).

Organic Compounds

Lindgren (16) determined gasoline and oil in water at a level of 0.1 mg/l with an accuracy of 0.05 mg/l. The method consisted of a $CHCl_3$ extraction, chromatographic separation, and infrared measurement at 3.38, 3.42, and 3.51 μ. If the zero absorption of the water is not known then the method could determine 0.2 mg/l. The author claims good separation of hydrocarbons from other contaminants by this procedure. The mass spectrometric method was used by Happ *et al.* (10) in the determination of volatile solvents in waste water. They found that dissolved or suspended solids

caused no interference since the vapor in the absence of air was only introduced in the mass spectrometer. It was found possible to apply the method to a single sample or to use a continuous monitoring system.

Ravin *et al.* (23) used a chromatographic method for the separation of mineral oil from stearins. A silica gel column adsorbate of the mixture was first eluted with 16 per cent isopropyl ether in isooctane to recover the mineral oils. The tristearins were recovered by eluting with 100 per cent isopropyl ether, and a mixture of 70 per cent ethyl ether in isooctane recovered the distearins. In order to elute the monostearins, a 20 per cent solution of ethyl alcohol in isopropyl ether was used. A high recovery value of the various fractions is claimed.

Daues and Hamner (7) determined acrylonitrile in industrial waste streams by concentrating and separating it from other components by an azeotrophic distillation with methyl alcohol, followed by a polarographic analysis. The authors claim that the method is applicable to a variety of industrial waste samples, regardless of the other components present. The method is sensitive to 0.1 ppm of acrylonitrile.

Mohler and Jacob (18) made a comparison of five different methods for the determination of phenolic compounds in water and industrial waste. An evaluation of the methods as to sensitivity, precision, accuracy, interference, reagents, and time elements showed the 4-aminoantipyrine procedure to be the best. When the coupling position of the phenolic compound is blocked, the ultraviolet procedure was found to be quite useful in either the ppm or ppb range. Sass *et al.* (26) determined 1-naphthol by reacting it with sodium cupribromide forming a blue-colored complex. No interference from 2-naphthol or other phenolic-type compounds was encountered in use of the method.

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Manganelli, R., and Brofazi, F., "Quantitative Determination of Volatile Acids by Paper Chromatography for Application to Sewage Sludge Digestion." *Anal. Chem.*, **29**, 1441 (1957).

O'Conner, R. T., Du Pre, E. T., and McCall, E. R., "Infrared Spectrophotometric Procedure for Analysis of Cellulose and Modified Cellulose." *Anal. Chem.*, **29**, 998 (1957).

Sorrels, M. F., and Reisen, R., "Identification of Some Marine Oil Constituents by Chromatography." *Jour. Amer. Oil. Chem. Soc.*, **34**, 131 (1957).

Metallic Ions

Ziegler *et al.* (31) determined Fe (III) by reacting it with 8-hydroxy-7-iodoquinoline-5-sulfonic acid. They found that by replacing the hydrogen atoms with a tri-n-butylammonium salt a more water-insoluble salt was formed, which could be extracted readily with isoamyl alcohol. The isoamyl extract gave an absorption maximum at 610 mμ, which could be used for the determination of Fe (III). The effective pH range is 2.5 to 7.5. The concentration of Fe (III) can be determined in a 25- to 50-ml sample up to 150 mμ. The authors also discuss interference from ether ions.

Somers and Garraway (27), in the determination of Cu with biscyclohexanone oxyldidrazone, found that a borate buffer gave better results than NH_4OH-NH_4 citrate buffer. The use of the borate buffer prevents an excess of NH_4 being present which hinders the formation of the Cu complex. The blue Cu complex formed develops in 10 min and is stable for at least three hr. The proposed method is unaffected by 100 μg of Fe and Al (III), Ni, Co,

Mn, Mg, Ca, Zn (all in II valence state) and by CRO_4^{-2}, PO_4^{-3}, and CO_4^{-}.

A number of methods have been proposed for the complexometric determination of Ca, in the presence of Mg. Kuznetsov and Mikhailov (14) used the tri-Na salt of 1-(2-carboxy-phenylazo)-2-hydroxynaphthalene-3,6-disulfonic acid. If Mg is present (concentration not stated) the titration is carried out in 0.1 M NaOH solution. The color of the indicator changes from yellow in the presence of Ca to orange-red. The authors say that the presence of methylene blue increases the sharpness of the end point. An almost identical method for the colorimetric determination of Ca was used by Kingsley and Robnett (12). They used the di-Na salt of 2-(5-chloro-2-hydroxyphenylazo)-4, 5-dihydroxy-2, 7-naphthalene-disulfonate, which becomes red in the presence of Ca. This reaction must also be carried out in a strongly alkaline solution and the authors claim good agreement with established methods for the determination of calcium. Tucker (30) found "Calcein" to be a more sensitive indicator than murexide. The titration is carried out at a pH above 12 in order to precipitate any magnesium present. The author was able to increase the sensitivity of the reaction by the addition of thymolphthalein and at the same time obtain a more satisfactory end point.

Doubek (8) determined nickel colorimetrically with diacetyl dioxine in an alkaline solution in the presence of sodium tartrate. The red Ni-complex color obtained is unusually stable. However, the optimum relation between the reagents used is essential.

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Christie, A. A., Kerr, J. R., Knowles, G., and Lowden, G. F., "The Colorimetric Determination of Cadmium, Chromium, Copper, Iron, Lead, Manganese, Nickel and Zinc in Sewage and Industrial Wastes." *Analyst*, **82**, 336 (1957).

Downey, T. A., "The Determination of Copper in Nickel Solutions." *Plating*, **44**, 383 (1957).

Gedansky, S. J., and Gordon, L., "Indirect Photometric Titration of Milligram Quantities of Silver with (Ethylenedinitrilo) Tetraacetic Acid." *Anal. Chem.*, **29**, 566 (1957).

Goto, K., "Colorimetric Determination of Aluminum in Industrial Waters Containing Iron." *Chem. and Ind.* (Brit.), 329 (1957).

Haslam, J., Squirrell, D. C. M., and Heskins, M., "The Titration of Bivalent Metals with the Disodium Salt of Ethylenediamine Tetraacetic Acid." *Analyst*, **82**, 971 (1957).

Kamote, T., Suenaga, S., and Nagata, S., "Determination of Silver in Water by Using Dithizone." *Eisei Kagaku* (Japan), **4**, 19 (1957); *Chem. Abs.*, **51**, 10305 (1957).

Kuemmel, D. F., and Mellon, M. G., "Ultraviolet Absorptiometric Determination of Boron in Aqueous Medium Using Chromotropic Acid." *Anal. Chem.*, **29**, 378 (1957).

Ruggieri, R., "Hydrazino-phthalazines. I. Organic Reagents for the Determination of Iron." *Anal. Chim. Acta*, **16**, 242 (1957).

Towiky, A. R., Issa, I. M., and Hewardy, I. F., "Colorimetric Determination of Manganese." *Anal. Chim. Acta*, **16**, 151 (1957).

Waterbury, G. R., and Bricker, C. E., "Separation and Determination of Microgram Amounts of Molybdenum." *Anal. Chem.*, **29**, 129 (1957).

Radioactive Elements

Goldin (9) determined strontium-90 by a series of precipitations, first as the carbonate, then as the chromate using Ba as the carrier. Two precipitations were made as the hydroxide and a final one as the carbonate. The carbonate was allowed to stand overnight to permit decay of Sr^{90} to Yt^{90}. After dissolving the precipitate in acetic acid it was extracted with 2-thienoyltri-fluoro acetone (5 per cent in benzene). The benzene layer was finally extracted with 1N HNO_3, the aqueous extract dried, and counted.

Kahn *et al.* (11) developed three methods for the determination of

radioactive cesium. These methods were then applied to the determination of this element in river water in concentrations between 10^{-4} and 10^{-8} mc/ml.

Thatcher and Barker (28) used an adaptation of the fluorophotometric determination of uranium in the routine analysis of water samples. The authors claim the method is relatively convenient, inexpensive, and reliable. The direct determination with the solid residue from 10 ml of water was made possible and purification of the sample is seldom required. The method used the high carbonate flux procedure, in which the flux solidifies in a dish with a white surface having a comparatively high reflectivity. The authors include a formula for correcting the non-quenched light. These same authors (1) modified the determination of the radium procedure so that less time was required. Although the method was less accurate for some waters, it is precise and accurate enough for water potability determination. The method involves a $BaSO_4$ carrier precipitation, filtration through a molecular filter, and activity counting after a prescribed aging period.

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Roshalt, J. N., "Quantitative Radiochemical Methods for Determination of the Sources of Natural Radioactivity." *Anal. Chem.*, **29**, 1398 (1957).

Sunderman, D. N., and Meinke, W. W., "Evaluation of Radiochemical Separation Procedure." *Anal. Chem.*, **29**, 1578 (1957).

Miscellaneous Papers

A number of miscellaneous papers have been published during the past year which may be of interest to those working in the field of sanitary chemistry.

Committee on Methods for the Analysis of Trade Effluents, "Methods for the Determination of Non-Volatile Matter Extractable by Light Petroleum and the Determination of Volatile Immiscible Liquids." *Analyst*, **82**, 123 (1957).

Committee on Methods for the Analysis of Trade Effluents, "Methods for the Determination of Aluminum and Zinc." *Analyst*, **82**, 975, 443 (1957).

Committee on Methods for the Analysis of Trade Effluents, "Methods for the Determination of Phenols and Sulfide." *Analyst*, **82**, 518 (1957).

Harris, J. C., "Analytical Test Methods for the Inorganic Portion of Synthetic Detergents." *Jour. Amer. Oil Chem. Soc.*, **34**, 199 (1957).

Holluta, J., and Haberer, K., "Odor Development in the Chlorine Dioxide Treatment of Waters Containing Phenols." *Gas-u. Wasserfach.* (Germany), **98**, 552 (1957); *Chem. Abs.*, **51**, 13271 (1957).

Jennings, P. P., and Osborn, E. M., "Quantitative Determination of Traces of Carbon Dioxide in Water." *Analyst*, **82**, 671 (1957).

Krishen, A., and Freiser, H., "Acetylacetone as Analytical Extraction Reagent." *Anal. Chem.*, **29**, 288 (1957).

Kulskii, L. A., Shevchenko, M. A., and Chupova, V. P., "Stability of Odors of Biological Origin in Water." *Gigiena i San.* (U.S.S.R.), **22**, 5, 16 (1957); *Chem. Abs.*, **51**, 18401 (1957).

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Novak, Z., "Application of Polarography to the Qualitative Purity Control of Surface Waters." *Wasserwirtsch.-Wassertech.* (Germany), **7**, 9 (1957); *Chem. Abs.*, **51**, 13275 (1957).

Scarano, E., "The Aluminum Electrode in Acid-Base Potentiometric Titrations." *Chim. Acta*, **16**, 365 (1957).

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7. Daues, G. W., and Hamner, W. F., "Determination of Small Amounts of Acrylonitrile in Aqueous Industrial Streams." *Anal. Chem.*, **29**, 1035 (1957).
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Sewage

Physical and Chemical Methods

Stones (142) reported on extensive experiments to determine the changes occurring during the settlement of sewage at a prolonged detention period. Experiments were made with liter samples of sewage allowed to settle for 18 hr. Biological effects of long detention were determined using 18-hr settling periods of liter sewage samples and comparing raw sewage and mercuric chloride sterilized samples. The per cent reduction in oxygen absorbed in 4 hr was generally taken to be the purification degree. The purification resulting from 18 hr of settlement of sterilized samples was only 8.7 per cent compared with 28.9 per cent for unsterilized samples, the 15.4 per cent difference being attributed to the biological action in the unsterilized sewage. Similarly, the reduction in organic nitrogen was 51.3 per cent for unsterilized sewage and 13.9 per cent for sterilized sewage. The net decrease in total solids reduction resulting from the reduced biological activity in the sterilized samples was 40.9 per cent. The per cent purification attributable to the biological action was found to increase with temperature. The addition of lime or sulfuric acid in small doses hindered the purification, since the precipitating effects were more than offset by the suppression of the biological action. Suppression of the biological action was similarly found to result from the addition of chromium. Neither mechanical mixing for 10 min nor aeration for 30 to 60 min prior to settlement was found to have any significant beneficial effect.

Chase (35) reviewed the status of flotation in the treatment of sewage and industrial wastes. Since coagulation and floc formation are extremely important parts of nearly all flotation processes, preliminary laboratory or pilot plant studies are needed to determine the best methods of flocculation. There are but few plants of any substantial size with more than a few years of experience in flotation for the treatment of sewage. Removals of 38 to 55 per cent of suspended solids, using overflow rates of 2 to 3 gpm/sq ft and detention periods of 10 to 20 min, have been reported. Applications may be the separation of activated sludge from aeration tank liquor and the thickening of sludge. Pilot plant studies are needed before any specific application. In industrial waste treatment, a considerable number of successful installations are treating wastes from the oil, paper, and food processing industries.

Boucher (21) discussed the applications of microstraining in water and sewage treatment. The principal application to sewage treatment is for polishing the final effluents of trickling filter and activated sludge plants. Microstraining is not effective for the removal of finely divided colloidal solids.

MacLeman (91) presented an outline of procedures for the design of grit chambers utilizing Parshall flumes or proportional weirs for the velocity control.

Biological Filtration

Biological Aspects

Hawkes (69) reported on an extensive study of biological films in trickling filters carried on at several sewage treatment plants in England. Certain parts of the study have been reported in previous reviews. It was a conclusion of the study that the nature of the films differs considerably and is dependent on the type of sewage treated. The films encountered on filters treating domestic sewage were predominantly bacterial with algae appearing on the surface. Filters treating trade wastes developed fungal growths in winter months.

The role of the macrofauna living within the filter slimes was also investigated. It was reported that, while the strength of the sewage appeared to determine the amount of film rather than the filter loading rate, temperature and the grazing activity of the macrofauna play a large part in the seasonal fluctuations of the bacterial films. The fluctuations of the fungal films, however, were not accounted for by differential grazing activity, but the grazing fauna was important in checking the winter fungal accumulation and probably assisted in the spring unloading. Attempts were made to control and to eliminate the insect larval population by use of insecticides, biological controls, variations in media size, alternating double filtration, and changes in the periodicity of dosing. It was concluded that the most effective method of controlling excessive film growth was by controlling the frequency at which the sewage is applied to the filter area. It was also found that the efficiency of the filter varied inversely with the film accumulation and that elimination of one insect larval species by treatment with an insecticide may, in some cases, result in the establishment of another more efficient grazing population.

An investigation of the organisms living in the slimes of various trickling filters was reported by Feldman (49). Fourteen species of molds, including 10 genera, were isolated. Four species of midge flies and two genera of mites were observed. The filter fly (*Psychoda*), nematodes, rotifers, and ciliate protozoans were found to be common inhabitants of the filter. The following fungi were identified: *Geotrichum candidum, Fusarium aquaeductum, Penicillium, Cephalosporium, Epicoccum, Cladosporium, Trichoderma, Aspergillus, Phoma,* and *Rhodotorula.*

Calaway (30) in reporting work which had been done on the intermittent sand filters points out that the principal workers in the biological treatment of sewage are:

1. Zoogleal bacteria such as *Zooglea ramigera.*
2. Aerobic spore formers such as *Bacillus cereus.*
3. Yellow bacteria such as *Flavobacterium aquatile.*
4. The so-called alkali-producing bacteria as represented by *Alcaligenes faecalis.*
5. The typical soil actinomycete, *Nocardia.*
6. The *Streptomyces.*

These bacteria are responsible for the breakdown of the various organic substances contained in the sewage. The zoogleal bacteria are probably most efficient in carbohydrate breakdown. The *Flavobacterium* and the *Bacillus* are chiefly responsible for the decomposition of organic nitrogen compounds. The role of the *Alcaligenes,* while not completely understood, is believed to utilize materials digested but not absorbed by other organisms. The *Nocardia* and *Streptomyces* are apparently humus digesters. The protozoan population of the filter, primarily members of the ciliate group, are bacterial feeders and most of them, particularly the holotrichs, are important because of their ability to consume and flocculate the bacterial turbidity.

The assimilation of humus materials (the residue of bacterial action) is accomplished by the metazoa present in the sand bed. The flat worms, annelid worms, nematodes, rotifers, water mites, insects, and insect larvae compose the majority of the metazoan population. The annelid worms present are close relatives of the tubifid worms (members of the oligochaet group), and having an insatiable appetite for sludges and slimes aid in keeping the bed open and accessible to oxygen.

Lawton and Eggert (83) reported that slime growths developed readily

on experimental filters dosed with highly saline sewage, provided the BOD loading was not excessive. It was noted that filter growths, developed from low salt content waste, suffered shock effects when high saline wastes were applied but that the slimes became acclimated to the high salt diet in one to five days. The same shock effect was noted when the saline content was suddenly reduced but the period of recovery was usually much quicker.

The ability of the microbes which inhabit the aerobic biological treatment systems to flocculate was reported by McKinney (96) as their most important characteristic aside from metabolism. Bacteria were found to flocculate more easily than the fungi. The role of algae in the treatment process is chiefly oxygen production and the removal of inorganic substances. Protozoa feed on the bacteria, thus reducing their number and aiding in providing a clarified effluent. The filter was found to be most efficient in removing the organic load when the bacterial population was in the logarithmic growth phase. However, flocculation is lowest during this period.

The breakdown of nitrogenous compounds by biological transformation was reported by Delwiche (42). The mechanisms of organic breakdown—deamination, decarboxylation, decomposition of sulfur-containing and basic amino acids, heterocyclic amino acids, purines and pyrimidines, and oxidation of amines—were discussed. The reactions were illustrated by chemical equations together with the metabolic products of numerous species. The fact that the formation of nuisance compounds can be prevented by maintaining an adequate supply of oxygen and the role of ammonia nitrification in providing nitrates (which in turn stimulate the growth of the algal flora, important oxygen producers) were stressed.

Using an experimental vertical screen trickling filter, Schulze (126) was able to study and examine microscopically the bacterial films associated with biological filtration. Using a settled sewage, strengthened by the addition of whey, heavy layers of film were developed up to a total thickness of 16 mm. After 41 days of operation, several different colonies of bacteria were apparent—creamy white, clear gelatinous, and light brown clumps. The first group was identified as *Beggiatoa alba*, the second, gram-negative rods of the zoogleal family, and the last, fungi. When the strength of the sewage was reduced (the whey omitted) and the tests repeated, the bacterial film which developed was quite different than previously observed. This film was light or dark brown in color and never increased to more than 1 to 2 mm in thickness. No pronounced development of the black anaerobic inner zone was observed and it is believed that the maximum depth of the aerobic zone is approximately 2 to 3 mm.

Operation and Results

The efficiency of biological filters using various methods of operation was reported by Peach (116). Two experimental filters, 6 ft in diameter, were filled with three layers of granite media. The bottom layer consisted of 1 ft of 3-in. stone on which was placed 3 ft of 2-in. media with 1 ft of 0.75 in. aggregate completing the filter. The filters were operated using alternating double filtration, two-stage operation, and standard recirculation of settled effluent. It was found that the two-stage operation gave better results than either of the other methods. Early in the study it was found that ponding of the primary filter became a problem and it was necessary to replace the 1-ft layer of 0.75-in. media with 2-in. stone.

During the 30 months the two-stage operation was being investigated, the BOD of the settled sewage being ap-

plied to the primary filter averaged 191 ppm and the hydraulic loading rate was 507 gpd/cu yd. The BOD was reduced to 58.6 ppm by the primary filter and to 20.4 ppm by the secondary filter, giving an over-all reduction of 89 per cent. The final effluent contained 12.2 ppm of nitrates.

It was also reported that the periodicity of dosing plays an important role in the prevention of ponding where the filters are operated at a high dosage rate.

Using a strong industrial waste and 6 Pyrex tubes, 3 in. in diameter, 6 ft long, and filled with 0.375- to 0.75-in. clinkers, Byrom (29) conducted an experiment to determine the effect of intermittent dosing on experimental filters. The rate of application was maintained at 100 gpd/cu yd throughout the experiment and the frequency of dosing was set at 1.5-, 2.5-, 8-, 12-, and 17-min intervals with one filter dosed by continuous drip for control. In order to eliminate the effect of individual filters, the periodicity of dosing for each filter was varied at random. In summarizing the results, Byrom notes that maximum removal, based on the percentage of standard 4-hr oxygen absorbed from permanganate, occurred when the dosing interval was set at 8 min. It is also noted that over-all average removal was higher when the filters were drip fed (61.0 per cent) than when the filters were fed intermittently (60.7 per cent).

Three methods of recirculation were investigated at Halifax in an attempt to determine an economical method of increasing plant efficiency. The results of this work were reported by Lumb (89). The variations in the recirculation procedure are described as follows:

1. True recirculation. Returning settled trickling filter effluent to the influent line of the same filter.

2. Pseudo-recirculation — Type I. Returning the highly nitrified effluent of one filter to the influent line of another filter.

3. Pseudo-recirculation — Type II. Returning the effluent from a "Simplex" aeration tank to the influent line of a trickling filter.

This work was first initiated on a laboratory scale and expanded to a pilot plant study utilizing the pseudo-recirculation (Type II) method when its attractive possibilities became evident. After favorable results were obtained from the pilot plant study, full-scale operation was undertaken. Based on operational data over a 12-month period, it was concluded that the full-scale filters were able to treat over twice the normal sewage loading and produce an effluent which was superior in all respects except that the nitrate content was low.

Tedeschi and Lucas (145) reported that an experimental up-draft filter was able to treat effectively sewage at several times the normally accepted loading rate. This filter, 7.5 ft. in diameter and containing 9.5 cu yd of media, was covered over and equipped with an 18-in. diameter stack or chimney. This innovation provided an up-draft through the filter which apparently accelerated the rate of oxidation.

Based on the assumptions that (a) a trickling filter is a self-regenerating absorption tower, (b) each unit depth of the filter will remove a constant fraction of the removable BOD applied to that unit depth, (c) removable BOD is the fraction of the observed BOD which can be removed by biosorption, and (d) the quantity of BOD that can be absorbed by one unit volume of filter has a maximum limit, Stack (139) developed formulae which give the theoretical performance of a trickling filter with and without recirculation. While the usefulness of these equations has not been substantiated, there is agreement between the theoretical curve and actual values. It is anticipated that the formulae may be

useful in interpreting and predicting trickling filter performance.

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Activated Sludge

Since the cost of compressing air is the major cost of power in an activated sludge plant, a great deal of attention continues to be directed to the study of oxygen transfer and aeration requirements. Bargman, Betz, and Garber (14) reported the air demands at the Hyperion plant were 60 per cent greater than at other high-rate activated sludge plants because of the high average sewage temperature, the long average raw sewage flow time (8 hr) to the plant, and the septic condition of the sewage. About 75 to 85 per cent over-all removal of BOD and suspended solids is obtained and the quality of the effluent is relatively independent of the strength of the raw sewage. They conclude that the high-rate aeration method suffers from a basic instability and requires close and careful supervision for best operation.

Friedman and Lightfoot (51) made a preliminary study of oxygen transfer to an aerated copper-catalyzed sodium sulfite solution to determine the effect of impeller geometry on rate of oxygen absorption. For the four-bladed paddle impellers, the rate of oxygen absorption was independent of air flow at a given impeller speed over a wide range of operating conditions. In this range oxygen absorption equaled $K_v \alpha N^3 D^5$ where K_v was the volumetric mass transfer coefficient of oxygen absorption, N the rate of rotation of the impeller, and D the impeller diameter. Only at very low values of N^3D^5 did an increase in gas rate increase K_v. Eckenfelder (46) discussed the mechanics of oxygen transfer and proposed a method for the design of aeration systems. Important factors include the oxygen saturation characteristics of the sludge-waste mixture, the magnitude and variability of the oxygen utilization rate, the operating temperature level in the tanks, and the oxygen transfer characteristics of the waste and of the aerating devices used.

Pilot plant studies by Budd and Lambeth (26) indicated that, as compared with conventional activated sludge, the use of high purity oxygen would permit a reduction of about 50 per cent in the secondary treatment area requirements and as much as 30 per cent in volume. The operating power requirements for both systems were essentially the same. Okun (111) found that, if long periods of zero dissolved oxygen were avoided, the level of dissolved oxygen did not affect the efficiency of treatment or the rates of activity of the organisms, as measured by the rates of oxygen utilization.

Ullrich and Smith (150) have reported on the operation of the biosorption process at Austin, Texas. This process consists of a short contact period of sewage with sludge, followed by reaeration of sludge. With an average sewage-sludge contact period of

38 min and 5.2 hr reaeration, more than 90 per cent removal of BOD and suspended solids was obtained. Ullrich (149) found that the biosorption process was less temperamental than conventional activated sludge and that it required less than half the aeration capacity. It is little affected by shock loads and there was no bulking or frothing. A similar process was successfully used for a modern shopping center, according to Burde (27).

Clinton (36) illustrated with two examples that small activated sludge plants are capable of handling seasonal peak loads and heavy shock loads. Preaeration should be provided; with very heavy shock loads, chemical precipitation may be used. Capacity of the aeration tanks must provide 30 cu ft per pound of BOD applied. Efficient air diffusers are important.

A pilot activated sludge plant (Kessner type) was studied by Sladecek (131) for nearly two years. The types of predominant protozoa in the sludge are given. The bulking of activated sludge was accompanied or preceded by a rise in the quantity of organisms in the sludge. A temperature of 7 to 13°C is considered as the optimum for stable purification. At temperatures below and above this range, purification falls off.

Vosloo and Finsen (151) conducted experiments on the additional purification obtained by aerating trickling filter effluent prior to secondary sedimentation. The humus sludge became activated, and effective oxidation of ammonia to nitrate was obtained. In addition, substantial reductions in bacterial numbers were obtained by this method of treatment.

A study of 11 contact aeration plants in New Jersey by Wilford and Conlon (157) indicated that the process is capable of efficient sewage treatment and can remove more than 90 per cent BOD and suspended solids. They reported that these plants have provided an adequate solution of the sewage treatment problems at realty developments.

Operating results for the high-rate activated sludge plant at Wuppertal-Buchenhofen, Germany, have been reported by Möhle (106). In this plant, air is added in large bubbles through 1.5-in. open pipe. The dissolved oxygen in the aerators was maintained at 0.5 to 1.0 ppm. The sludge contained many bacteria, a few flagellates, but rarely other protozoa. Biologically it was hardly activated sludge. With a 1.6-hr aeration period, an average of 60 to 72 per cent BOD was removed from the settled sewage. Air consumption varied from 430 to 700 cu ft per pound of BOD removed.

Eckenfelder and Porges (48) discussed the various factors in organic waste disposal by the activated sludge process and presented simplified computations for plant design.

Frothing still causes trouble in activated sludge plants. Sparr (138) describes the causes of foaming and methods for its control. He believes that an effective and economical defoamant must be a water-insoluble liquid with a specific gravity less than water. It must have a low pour point and a low and nearly constant viscosity. In addition to good "knockdown," the defoamant must have a residual effect.

Disinfection

The U. S. Army Chemical Corps continues to emphasize the general subject of nuclear radiation for the treatment of sewage. In January 1957 (11) it was announced that disinfection of sewage by means of ionizing radiation was to be undertaken under their direction at the Armour Research Foundation of the Illinois Institute of Technology, Chicago, Illinois. In July of the same year an announcement was made through the trade journals (12) that another research project of the same general nature at the Armour Research Foundation, also under the jurisdiction of the Army Chemical

Corps, has indicated that nuclear energy might be used to sterilize sewage for 0.25 cents per gallon. In the same report it was stated that about 2,000 times as much radiation is required to kill bacterial spores as is needed to kill a human. The treated sewage, however, would not become radioactive enough to be a public health menace.

The viability of *Escherichia coli* to heat and chlorine has long been a debatable subject. Chambers and Tabak (34) heated *E. coli* suspensions at 71°C for 30 sec. These suspensions, when no survivors were left, showed no growth in subsequent incubation in metabolites. Similarly, when these organisms were chlorinated until no survivors were left, no growth was obtained upon subsequent incubation in metabolites. When a few organisms survived chlorination, large increases in growth occurred on incubation with metabolites. These results should be especially valuable when the question of bacterial development of a tolerance to disinfection is under debate.

Dunlop (45), based on data obtained while investigating the bacterial content of sewage used for irrigation purposes, feels that there is a direct correlation between MPN of coliform organisms and enterococci in water and the incidence of *Salmonella*. Unless the coliform count is kept below 23,000 per 100 ml, *Salmonella* may be found. In this work it developed that *Ascaris* ova and *Endamoeba coli* were reduced by approximately 50 per cent in the primary settling phase of the treatment. Only 20 per cent of the *Ascaris* ova remained in the chlorinated effluent but 46 per cent of the cysts remained. These animal parasites proved to be considerably more resistant to chlorination than the bacteria.

In Great Britain, subsequent to World War II, the infections of cattle with *Cysticercus bovis* (the larval stage of the human tapeworm) has been increasing at an alarming rate. Research (129) to prevent the disease has led to the sewage treatment plant. Here it was found that air-dried sludge does not kill the ova. Rapid sand filtration and microscreening will remove up to 90 to 95 per cent of them.

It was reported (7) that iodine in concentrations used for drinking water disinfection will kill amoebic cysts. Use of iodophors, mixtures of iodine and a carrier, increases its stability in water and may make its use more popular. The amber iodine color, as long as a solution is effective, is a unique and useful property of the iodine preparations.

Sawyer (122), working in the laboratory under ideal conditions, and in the field where conditions are usually far from ideal, has found that sodium hypochlorite may be more effective on an equivalent chlorine basis than gaseous chlorine when applied to a sewage. He attributes this to the side reactions which take place in the local low pH areas near the point of chlorine injection. In these areas a portion of the chlorine is used up rapidly, leaving just that much less in the sewage to kill bacteria.

Besselievre (19) adds this word of caution where hypochlorites are used —watch its strength. He says that sodium hypochlorite loses about 1 per cent of its available chlorine strength per week. Thus, storage facilities and truck delivery schedules should be carefully calculated.

Sludge Digestion

Theory and Mechanism

The problems of determining the exact sequence of events in anaerobic fermentation of sewage were considered by several authors. Kaplovsky (79) noted that the abundant intermediate products of decomposition—the volatile acids—are the product of a diversified group of organisms which are difficult to isolate as individual strains. Bloodgood (20) suggested

further that a mixed culture may be absolutely necessary to convert complex organic matter to methane, which most writers believe results from the decomposition of the volatile acids. The value of volatile acids determinations in digester operation led to an effort to find less time-consuming and complicated methods for their analysis. Frook (52) described a direct phosphoric acid distillation method using Kjeldahl apparatus which recovers more than 98 per cent of the volatile acids (acetic, propionic, n-butyric, and n-valeric) expected in solution in digester sludges. The entire procedure requires but 2 hr. Calculation of results, the author concludes, should be based on propionic rather than acetic acid. Development and test results of a manometric apparatus large enough to measure oxygen uptake of various substances which occur in sewage were reported by Coaker and Murray (37). This procedure employs two 3-necked, 1-liter flasks connected to a manometer which measures differences up to 70 cm.

Inhibition of the sludge digestion process was reported. Dietz (44) noted a 50 per cent reduction in digester gas production when 200 mc of radioactive sulfur per pound of sludge was introduced. Mixed fission products caused a reduction of 35 per cent; radioactive phosphorus, 13 per cent; while radioactive iodine was not inhibitory. At 50 mc per pound none but the mixed fission products caused any decrease. Stander and Gien (140) determined that copper in the range of 4,000 to 13,000 ppm is toxic to sludge digestion. Eighteen per cent of the added copper passed into the raw sludge, of which 97 per cent accumulated in the solid phase of the digester contents. When digestion was reestablished, after failure due to copper toxicity, acclimatization to copper was observed upon the resumption of copper feeding. In laboratory scale systems sludge digestion was inhibited (53) by 33 ppm creosote. In South Africa, Gien *et al.* (58) found poor digestion of night soil to be caused by high concentrations of ammonia and/or dissolved solids. When at least eight volumes of water were added to one of night soil, anaerobic digestion proceeded satisfactorily.

Proposals to dispose of blood from a 300-animal abbatoir were abandoned when experiments reported by Singleton (130) showed high CO_2 and H_2S production, excessive scum and foam, high BOD of supernatant, indescribable odor, and greatly increased digestion time.

Greene (64) observed progressive reduction in gas production per pound of volatile solids over a period of years. The condition was attributed to detergents although no supporting evidence was submitted. Textile wastes were observed by Anderson (2) to decrease gas production until digester failure occurred and textile wastes were excluded from the sewers. In Germany, according to Liebmann (85), gas production has been increased by the addition of leaves. Gas production from agricultural wastes has also been produced. Digestion was found ineffective in killing the bacillus of tuberculosis. Digested sludge dried for five weeks was reported by Greenberg and Kupka (63) to contain viable organisms.

Horasawa (75) found that the addition of fish materials or allied animal materials in garbage is useful in accelerating gas production of digesting night soil. Night soil digested at 30° C for 30 days produces 130 to 200 ml of gas per gram of volatile solids. The amount of gas produced from fish materials digested with night soil was 200 to 300 ml of gas per gram of volatile solids.

Effect of Additives

Carlson and Cornell (32) reported that a small digester receiving 4,500 lb of ground garbage per week devel-

oped 3 to 3.5 ft of scum and showed evidence of poor digestion over a period of two years. Enzymes were added at a rate of about 7 lb per month. After 9 months the scum had disappeared and the sludge appeared well digested. Pearson *et al.* (117) found, however, that carefully controlled experiments reported in the literature showed no beneficial results. Experiments run by members of this committee confirmed these results and led to the conclusion that the biocatalytic additives tested had no beneficial effect on sludge digestion or in grease liquefaction. In fact, a decrease in grease digestion and an increase in volatile solids were observed.

New Developments

Microbiological production of sulfur to meet the sulfur shortage in the United Kingdom was attempted on an experimental scale by Butlin, Selwyn, and Wakerley (28). A scheme was developed whereby a portion of raw sludge was subjected to methane fermentation. The gas produced from this step was used to sweep out the H_2S produced from the reduction of sulfate in which the remainder of raw sludge served as hydrogen donor. The sulfate content of the raw sludge was augmented by the addition of wastes high in sulfate content. Burde (27) described a unique plant for a 1,400-employee shopping center in which excess raw sludge, after a 90-min reactivation, is aerated in a digester for about 6 days. The resulting sludge is stable and easily dewatered, containing 1.6 per cent solids in comparison with 1 per cent in the influent. Provision is made for a 28-day storage of aerobically-digested sludge. Golueke, Oswald, and Gotaas (61) compared the value of raw sewage sludge and green algae as a source of nutrient in anaerobic digestion. Algae grown on domestic sewage were separated and digested. Best digester performance occurred at 50°C with 11- to 30-days digestion. The maximum permissible load was not determined but is greater than 0.18 lb volatile matter per cu ft culture volume per day. Approximately 8 cu ft of gas were produced per pound of volatile matter. This averaged 30 per cent CO_2 and 65 per cent CH_4.

In a new proprietary device described by Forrest (50) sewage sludge is digested anaerobically with continuously circulating digester gas introduced at 0.125 to 2.0 cfm per foot of the longest horizontal cross-sectional dimension of the tank. Sludge is removed at a low rate and settled in a second tank. Minish (105) describes the use of a heat pump to heat a digester so that the gas produced might be sufficient to flash dry the digested sludge.

Digester Operation and Maintenance

Morgan (107) noted that gas recirculation is a more stable process than unmixed digestion, and found the rate of mixing to be related to the tank diameter.

Lohff (88) discussed the importance of gas and sludge recirculation to accelerate digestion and thus reduce the cost of the digestion plant. Proper procedures call for recirculation of sludge from one stage to the influent of the preceding stage, and for permitting sedimentation of the more completely digested sludge, in the final stage. Some of the principal causes of failure of digesters were discussed. Accumulations of grit and trash causing loss of capacity and interfering with heating were common. Schreiber (125) reported a volume loss of 15 per cent in 12 digesters at Washington, D. C., in about 16 years. Gas and water injected at high pressure through flushing nozzles, sampling wells, and pipes inserted through relief covers were combined with a nonclog pump inserted through opening for gas dome to remove accumulation. Only 1 of 12 digesters retained its pip-

ing intact. Sections of all piping in the others had fallen under weight of grit and trash. Lee (84) reported the digester of a small plant to be half-full of gravel. Overloading led to refurbishing of the plant. Sudden failure of two plants at Norfolk, Virginia, was reported by Miller and Barron (104) to be caused by raw sludge overload, scum build-up, and the restriction of heat circulation by scum. Experience showed that whenever the gas analysis revealed more than 35 per cent CO_2, trouble was imminent. With a constant CO_2 watch, it has been possible to take effective action, whereas pH and volatile acids fail to show critical conditions until it is too late.

Causes of failure of several digesters receiving industrial wastes were summarized (56). Cases were cited in which feathers formed a scum blanket; solvents and toxic compounds depressed gas production; citrus wastes inhibited digestion and produced scum; and chromium, cadmium, copper, cyanides, etc. destroyed digestion.

As a result of experience in starting up new digesters, Shafer (128) concluded that initial fresh solids feed should be limited to 10 per cent of design capacity; temperature should be raised to 90–95° F before introducing fresh solids; and seeding should be done if possible. Lime treatment was found to be effective if volatile acids were above 3,000 ppm and if addition is continued until volatile acids are reduced below 1,000 ppm. Gas with 60 per cent CO_2 was successfully burned in heaters at low pressure, although a maximum of 35 per cent was found suitable for gas engines.

Digester Design

Experiences described by Schreiber (125) led to the conclusion that bottom slopes in digesters should be steeper; that sampling tubes and piping should be located to facilitate the objective of obtaining true sample contents; and that adequate facilities for cleaning should be incorporated into digester design. Langford (82) cautioned that while accelerated digestion is possible, the designer should consider field limitations such as power failure, sickness of personnel, etc. He warned that a reduced degree of digestion in the interests of high-rate digestion can be dangerous, and differentiates between high-rate, which may be only partial digestion, and accelerated digestion involving recirculation of sludge or gas. Lynn (90) published a nomograph by which the designer may rapidly compute the gross dimensions necessary to meet any required effective volume of digester; also a nomograph for the rapid calculation of heat requirements of a sludge of any particular concentration applied at a given rate per day and maintained at any given temperature.

Orford (113) presented a committee report suggesting the adoption of specified standard units for the expression of digester loading, detention period, reduction of solids, gas production, etc., to replace the multiplicity of units now used by various designers.

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Sludge Disposal and Utilization

Sewage sludge processing and disposal patterns were discussed instructively by Meier (99). He concluded that the sludge disposal facilities of primarily residential towns of 25,000 population or less will continue to practice anaerobic digestion followed by drying beds. In larger plants vacuum dewatering followed by processing for preparation of soil conditioners will receive increased interest.

Stolley and Fauth (141) described a continuous process designed to extract and recover grease, to dewater the fresh sludge, and to recover the solids for soil conditioning. Cost of sludge disposal in this way was estimated at $36 per ton of dry solids. The process was not considered economical until the return for the dry meal exceeded $10 per ton and a market could be found for the black fat. Its composition and fuel value were thoroughly analyzed. For drying sludges, Heymann (73) has obtained a patent covering an endless vibrating filter media belt.

Interesting innovations for sludge disposal were reported in several articles. In Los Angeles (109), a 7-mile long, 20-in. diameter ocean outfall discharges sludge to an underwater canyon at a depth of 320 ft. The replacement of the present sewage irrigation farms in Berlin, Germany (38), involves the construction of modern sewage treatment plants in which primary and activated digested sludge is to be vacuum filtered and drum-dried. Treatment efficiencies and operating costs are given by Haseltine (68) for a primary plant in which digested sludge is elutriated, vacuum filtered, and the cake hauled away by farmers. The combination of industrial wastes with sewage frequently does not permit digestion of the sludge. Thus, Saunders (121) describes the handling of fresh sludge for barging to sea.

Hydraulic handling of incinerated solids is the most economical according to Hampton (67), provided adjacent land is available. Pneumatic methods are the most expensive. Brisbin (23), studying the flow of concentrated sewage sludges in 4- and 6-in. pipes, concluded that at 65°F fresh primary sludges at 8 to 10 per cent total solids concentration exhibit 6 to 8 times the friction losses of water. At the same solids concentration digested sludges are less resistant to flow than fresh sludges.

Sludge Concentration

Behn (16) critically reviewed the theory of sludge thickening on an experimental basis. Qualitatively, the mechanism of thickening involves zones of hindered settling, transition, and compression. Quantitatively, sludge concentration appears to be described best as a function of settling velocity. Behavior of a suspension in the compression zone appears to be analogous to soils consolidation. Eckenfelder and Melbinger (47) analyzed the theory on a similar basis.

The present experience concerning flotation as a means for thickening sludges was reviewed by Chase (35). Dissolved compressed air flotation concentrates primary sludges to 6 or 7 per cent total solids and activated sludges to 3 per cent total solids in about 30 min. Where applicable, flotation should require one-sixth of the total area of sedimentation tanks.

A two-stage sludge-thickening and concentrating device was described by Smith (132). The end product resembles the discharge from a sludge vacuum filter, but power and chemical costs were claimed to be lower.

Purchas (118) dealt with the sizing of different types of rotary vacuum

filters from laboratory data. Cornell *et al.* (40) related experiences with a continuous rotary belt filter, dewatering water softening, black liquor, photographic plant, and corn refining plant waste sludges. Determination of optimum conditions for each sludge was necessary in each case. The slurries resembled sewage sludges in that the maximum attainable rates ranged from 4.5 to 14 psf/hr.

At Union City, Tennessee (93), the storage problem of fresh primary activated sludges prior to vacuum filtration was solved by installing sludge drawoff lines at various levels of the tank and using mild aeration to minimize stratification. Toward the end of the initial 18-months' operating period, chemical dosage has leveled off at about 4.0 per cent ferric chloride and 6.0 per cent calcium oxide on dry matter. Average yields were about 3 psf/hr using the coilspring filter medium. Bubbis (25) described experiences with stretching of the coilspring filter medium at Winnipeg, Canada. This phenomenon was due to scaling in the helixes of the coils. Factors contributing to the scaling were the type of sludge, water supply, and conditioning. The stretching effect was controlled by changing the cross-sectional shape of the wire used to manufacture the coiled springs and by occasional descaling with inhibited hydrochloric acid. During the first year the average chemical dosage was 2 per cent ferric chloride and 9.0 per cent calcium oxide on dry matter. The yields varied from 4.5 to 7.5 psf/hr for primary digested elutriated sludge.

Vacuum filtration experiences using fixed cloth filter media were described by Baron (15) and Locke (86). Using not more than 2 per cent ferric chloride on dry matter and primary digested elutriated sludges, a yield of about 6.5 psf/hr was reported. Preliminary tests indicated synthetic cloths to be superior to wool. However, Taylor (144) did not find a synthetic cloth to be superior to flannel.

Caster (33), Gerdel (55), and Bubbis (25) reported that in spite of elutriation, the use of lime in addition to ferric chloride reduced chemical costs, and in one case increased yields from 2 to 4 psf/hr. Taylor (144) investigated conditioning, elutriation, and filtration of a primary digested sludge containing oily industrial wastes. Contact time after addition of ferric chloride appeared to be optimal after 20 to 40 min. In the elutriation process, compaction and clarification of supernatant could be improved by adjusting the pH to 5.5 with sulfuric acid. Crundall (41) described the use of aluminum chlorohydrate. The material has the empirical formula $Al_2(OH)_4Cl_2$, is marketed in solution containing 15 per cent Al_2O_3, and has a pH of about 3.0. The chemical is being used to condition sludge prior to vacuum filtration. Drying bed experiments with various types of sludges indicate that dosages of 0.5 to 3.5 per cent, as Al_2O_3, decreased drying time 50 per cent. Results of laboratory experiments claim 1 per cent as Al_2O_3 to be as effective as a ferric chloride dosage of 3 per cent as Fe_2O_3.

Pressure filtration of sludge in Great Britain was described in detail (120). Sludge from a community of 175,000 people is conditioned with 10 per cent copperas and 36 per cent lime. The conditioned sludge is transferred to 1-ton filter presses and is kept under pressures up to 100 psi for 3 hr. Cake of 45 per cent total solids is produced from 7 per cent sludge. Operating costs were divided as follows: 45 per cent—chemicals, 40 per cent—labor, 10 per cent—cloths, 4.5 per cent—power, and the remainder—maintenance.

By conditioning a fresh primary and trickling filter sludge with about 6 per cent ferric chloride, the required drying bed area was reduced to 700 or 900 square feet per 10,000 population

(134). Bowers (22) required 5,694 sq ft per 10,000 population for a digested sludge with exemplary drying bed care but without conditioning. At Richmond, England (9), dried sludge is removed from beds by manual loading of dump buckets moving on overhead rails. Tests are being conducted with bed covers of asbestos cement sheeting.

Sludge lagooning appears to be the preferred method of disposal of some primary treatment plants in California which receive domestic and cannery wastes (17)(24).

Sludge disposal costs involving incineration were analyzed by Mick and Linsley (103). Per ton of dry solids removed, costs at Buffalo were about four times and at Cleveland about twice those at Detroit and Minneapolis-St. Paul. The lesser costs were $20 per ton of dry solids. Process controls are important to economy. Of the total laboratory costs at Minneapolis-St. Paul, 37 per cent was assigned to sludge disposal, 22 per cent to sludge concentration and vacuum filtration, and 15 per cent to incineration and ash disposal. The air pollution problem connected with sludge incineration can be alleviated best by (a) proper stack heights, (b) high temperature deodorization (1,200°F), and (c) centrifugal collectors for fly ash removal (62). From flash drying and incineration equipment 47 weight per cent of particulates ranged in size between 7.5 and 60 μ, while 30 per cent were below 7.5 μ. Owens (115) insisted that multiple hearth furnaces do not produce odors. Heat values of different types of sewage sludges are described. In general, fresh sludges have a greater heat value than digested sludges.

Sludge Utilization

Composting of sludge together with refuse for preparation of soil conditioners received increased attention during the past year. Orenstein (112) considered agricultural sludge disposal a public health hazard unless it is composted, completely dried, or used only on non-root crops under closely supervised and controlled conditions. First-hand reports of present practices in underdeveloped areas were published by Henderson (70)(71) and by Heukelekian (72). In South Africa the recovery of all organic wastes for agricultural utilization is encouraged by law (43)(80). Composting experiences of digested sludge with raw garbage in windrows were related by Straub (143). Sorting and screening are done subsequent to composting. A patent has been granted Geraghty (54) for a similar process.

From diffusion rate experiments McCauley and Shell (94) concluded that diffusion cannot supply oxygen at a sufficient rate to maintain a completely aerobic bacterial population at a depth greater than 2 to 3 in. The high-rate composting process continued to be investigated by Wiley (155) (156). The course of decomposition proceeds through an acidic (pH 4.5) and mesophilic phase to an alkaline (pH 8.5) and thermophilic phase. Such items as moisture, temperature, aeration rates, addition of lime or acetic acid, and continuous loading were investigated. It appears that a five-day cycle is feasible. Snell (136) (137) reviewed the various available processes and recommended only three to further development: windrowing with forced air, bin composting with forced air, and mechanical composting in three stages.

Sciarone and Lunt (127) concluded that digested sludges can be incorporated into soils at a rate of 25 per cent by volume. Such quantities make sufficient nitrogen available to sustain a planting for several months. Steaming of composts of sludge with rice hulls or wood shavings needs to be followed by irrigation prior to planting in order to remove toxicities. Additions of composted refuse and sludge

to a slightly clay sandy soil up to 133 tons per acre showed a definite increase in the yield of potatoes (up to 300 per cent), celery, and onions, but not for tomatoes (152).

A report by Merz (101) was concerned with the land disposal of liquid digested sludge near San Diego, Calif. Farm land showed no deleterious effects after three consecutive applications of 60 to 300 tons of dry solids per acre. Following air drying of each application, the sludge was plowed under and subjected to leaching by irrigation prior to planting. Replicate plot studies using barley showed that 400 lb of ammonium phosphate yielded about as much as 25 to 100 tons of sewage solids. The sludge increased the moisture-holding capacity of the soils. At the present time all of the San Diego sludge is being used for reclamation of 56 acres for park development. Sludge is applied at loadings up to 300 tons dry solids per acre. A similar reclamation program in New York City is saving almost $1 million when considering savings in costs of natural top soils and in barging operations (123). In Toronto, Canada (10), a fertilizer company has contracted to buy up to 6,000 tons per year of vacuum filtered and dehydrated primary digested sludge.

Dried activated sludge was compared with soy bean oil meal on basis of amino acid composition, protein content, digestibility, and biological value (66). Activated sludge had a lower apparent digestibility in sheep and a higher biological value.

In seeded aerobic and anaerobic digestion experiments with fresh sewage sludge, Neujahr (110) evaluated the effect of several antibiotics, added up to 0.25 per cent of dry matter, on the production of vitamin B_{12} activity. Aureomycin and terramycin were stimulating if added when the sludge had reached pH 6.5. Neomycin, active or inactive, had the least effect, while inactivated penicillin stimulated most B_{12} factors anaerobically. Kamikubo *et al.* (77) investigated vitamin B_{12} content of activated sludge, using a bioassay method with *Lactobacillus leichmannii*. The vitamin B_{12} content was not affected significantly by sludge storage for 24 hr, cobalt sulfate additions up to 40 ppm, or by sodium fluoride. It was stable to drying by infrared rays, but not to temperatures of 100°C. The highest vitamin contents were observed between September and November, and the lowest in June. In the preparation of crystalline vitamin B_{12} (78), activated sludge was extracted with boiling water, mixed with activated carbon, and the carbon was eluted with 50 per cent acetone The vitamin was purified by several recrystallizations before and after treatment with ion exchange resins. Janicki *et al.* (76) isolated vitamin B_{12} from digested sludge, using slightly different techniques.

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Detergents

Barden and Isaac (13) used laboratory-scale trickling filters and a Warburg respirometer to test the effects of Teepol, lauryl sulfate, alkyl benzene sulfonate, cetyl pyridinium bromide, and Lissapol. They found that the detergents impaired filter performance by overloading the units with carbonaceous material. Suppressions of oxygen transfer by the detergents also interfered with filtration. Trickling

filters originally producing a good effluent would not be adversely affected by detergents in concentrations under 20 ppm (active matter).

The removal of anionic synthetic detergents by trickling filters has been reported by Smith (135) as a result of studies undertaken in Keighley, England. The results indicate that a 100-ft filter, operating without recirculation, removed 83 per cent of the synthetic detergent applied even though the filter was overloaded and would not produce a satisfactory effluent. When recirculation was added, the percentage BOD removal increased but the amount of synthetic detergent removal dropped to 80.8 per cent. Tests made at the Oxenhope Sewage Works employing straight filtration revealed that 75.7 per cent of the synthetic detergent load was removed. This plant was underloaded and was producing a settled filter effluent having a BOD of 4 to 6 ppm. It was concluded that the trickling filter is capable of removing a large proportion of the applied synthetic detergent and that the amount removed is not connected with the organic loading but does appear to vary with the character of the sewage.

Mann and Herbert (92) studied the effect of detergents on trickling filters and activated sludge in laboratory-scale experiments. A mixture of equal weights of seven proprietary washing powders (consisting of alkylaryl sulfonates) used in Britain was prepared and added to artificial sewage. In the trickling filter experiments the concentration of the detergents added was 26.5 ppm. The dosing rate of the filters was 60 gpd/cu yd (Brit.) and the average BOD in the artificial sewage fed was 187 ppm. Determination of the detergent content in the effluent from the trickling filter followed by sedimentation showed that initially a removal of 80 per cent was obtained which declined to about 30 per cent between the 3rd and 5th weeks of operation. The removal increased to 53 to 72 per cent thereafter until the end of the experiment in 24 weeks. The removal of synthetic detergents by the activated sludge process behaved in the same general manner except for some quantitative differences by the trickling filters. The BOD in the effluent with and without the addition of detergent showed no difference for the trickling filter and activated sludge process.

Roberts (119) found at the British Luton and Letchworth Works that synthetic detergent removal was not necessarily associated with BOD removal. He observed that reduction in detergent concentration occurs to a greater degree in an oxidizing than in a flocculating system. Also, the efficiency of detergent removal is greater in activated sludge units than in trickling filters.

During treatment by diffused air-activated sludge process, Lockett (87) found that 20 ppm (active matter) Santomerse had a definite retarding effect on the purification process; Teepol had virtually no effect at this concentration, and Lissapol N had only slight adverse effect.

Foaming could be controlled by use of Foamrex W in concentration of 3 ppm on sewage flow basis, applied at the inlet end of an aeration channel. Tests showed that it was more economical by applying reagent to the mixed liquor during its flow through the aeration unit at drip-feed intervals of 200 ft.

Shell Anti-foam No. 1 was found to give satisfactory results. Effluents, using both reagents, supported fish life without dilution.

On a laboratory scale, Munro and Yatabe (108) studied the frothing characteristics of synthetic sewages containing dextrose, starch, and peptone, with additions of fat, lauryl sulfate, soap, alkylaryl sulfonate, or mixtures of these. Synthetic sewage containing 75 ppm each of dextrose,

starch, and peptone, with (a) 37.5 and 375 ppm of soap and (b) 35 and 350 ppm of fat, showed practically no tendency to froth. Sodium lauryl sulfate (37.5 ppm) in a similar sewage base gave a temporary increase in froth formation after aeration for 2 to 4 hr, with no frothing after 24 hr. Fab (30 ppm active sulfonate) had considerable frothing ability which decreased but was still appreciable after 20 days of aeration.

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Lagooning

The interest in the fundamental biological and engineering principles in disposing of and possibly reclaiming sewage by the use of lagoons has been continued during 1957. McKinney (97) uses the term "single chamber oxidation pond" as contrasted to the "Swedish oxidation pond system," which consists of four successive ponds, the last one being equal in area to the first three combined. The last pond serves as a habitat for crustaceans that feed on the algae developed in the preceding ponds, thus producing an effluent free of algae and high in food for fish. Recirculation of the effluent from each pond before passing on to the succeeding pond is an important feature of the system. Wennström (153) gives a detailed description of such a system for the city of Lund, Sweden, as to dimensions, operation, and the resulting effluent. The flow is 525,000 gpd to a system of 4 ponds, having areas of 1.3, 1.1, 1.0, and 3.9 acres, respectively, with an average depth of 2 ft. The sewage is recirculated 6 to 7 times, giving a detention time of 1.2, 1.6, 1.1, and 4.8 days, respectively. The BOD is reduced from 158 ppm to 20 ppm. *Escherichia coli* are reduced from 100,000/ml to 30/ml. The purification in the individual ponds changes with the season but the over-all BOD reduction is fairly constant. The major species of bacteria, algae, and protozoa are identified, and their numbers are correlated to purification efficiencies by means of curves. The lower organisms predominate in the first pond, and the higher forms increase as the conditions of growth improve in the succeeding ponds.

Oswald *et al.* (114) have made detailed fundamental studies of algae and their functions in lagoons. In the laboratory where the apparatus used and the conditions of lighting, temperature, and substrate could be closely controlled, equations correlating these conditions with performance of algae were developed. This knowledge was then used for the design of outside pilot plants of various dimensions. The information thus gained was developed into fundamental principles correlating temperature, depth and size of lagoons, types of algae and their numbers, oxygen production, and reduction of BOD. Gloyna and Hermann (60) have studied the life history

and activity of algae as applied to sewage treatment in aquaria in which food, lighting, temperature, and recirculation could be closely controlled. From the analysis of sewage entering the aquaria, the analyses of aquaria contents and effluents and the study of algal types and numbers, the performance of these aquaria could be deduced and correlated with algae life. This information was used in the controlled feeding of outdoor lagoons of different sizes, and their performance was then used to develop factors for practical lagoon design. The practical conclusion as to depth of a lagoon system based on the preceding two studies is 4 ft, as applied to conditions similar to those in Texas and California. An investigation by Merz *et al.* (102) made of an existing installation at Mojave, California, found a depth of 10 ft needed in an additional lagoon of 0.57 acre to the two existing lagoons, each 0.15 acre in area and from 5 to 10 ft deep. This depth was needed as the lagoon effluent was to be used for the irrigation of 25.0 acres of pasture and the excessive evaporation of 116 in./yr would exhaust the water of a standard 4-ft depth lagoon. A detailed study of types and numbers of algae in the individual lagoons, the suspended solids and dissolved oxygen of each lagoon, the reduction of coliform organisms, and BOD is given. The flow patterns as affected by prevailing winds were also studied. As reported by McKinnie (98), Santa Rosa, California, added stabilization ponds to its 5 mgd treatment plant. These ponds provide 14 days detention, and their effluent may be used for irrigation or discharged into Santa Rosa Creek, which enters the Russian River. During 1954–1955 the MPN of coliforms of the pond discharge was 6.2; during 1955–1956 it was 1.9. Water hyacinths in the ponds became troublesome. Removal by drag-line had to be used after hand removal proved too costly, and spraying with 2,4–D was unsuccessful. A study of pond algae showed a disappearance of these during the spring of 1955 and of 1956. The algae were succeeded by *Daphnia* in both instances. Also in both instances there was a decrease in DO and in BOD reduction. Wilcox and Cruickshank (154) reported a similar use of stabilization ponds to supplement sewage treatment at Ukiah, California, on the Russian River. To care for the needs of the rapidly increasing population of the city and the immediate surrounding area, a sanitation district was to be created, contributing the sewage to a plant to be built by the city and discharging the effluent into the Russian River. The regional water pollution control board forbade this practice during the bathing season. The plan was changed so as to include stabilization ponds of sufficient volume to retain the treated sewage from May 1 to September 30. The plant itself will have primary sedimentation, trickling filters, final sedimentation, and sludge digesters.

A study of oxidation ponds in the Dakotas by Towne *et al.* (148) gives details of construction, operation, and results, as applying to the northern plains. The study was extended over a year to note the effect of deep freezing during the winter and re-establishment of aerobic conditions during the spring. A study of varying light intensity during the year and at different levels, and its effect on photosynthesis and consequent treatment results, is reported. This study, while particularly applied to the Dakotas, is fundamental in nature. From northward across the border from the Dakotas, Schaeffer (124), Lackie (81), and others (3) report of sewage lagoons replacing standard treatment plants for many small towns of the prairie provinces of Canada. Even cities like Swift Current, 10,000 inhabitants, and Regina, 90,000 inhabitants, expect to adopt lagoon treatment. The information as to size, depth, loading, and operation

of oxidation lagoons is adapted to Canadian conditions and is complete and of a practical nature. It is interesting to note that the minimum depth recommended is 5 ft, so as to allow for a 3- to 4-ft ice cover. Hopkins and Neel (74) discuss fundamental principles of design, operation, and performance of sewage lagoons in the Missouri basin states. A tabulation is included of all lagoons, giving the population contributing thereto, the number of lagoons in each system, and their area.

A small but effective oxidation pond installation is reported by Gidley (57) brought about by the overloaded septic tank of a sanitarium, the effluent from which entered a recreational stream. An oxidation tank designed for a BOD load of 40 lb per day/acre was built to receive this septic tank effluent. At present this pond receives 30,000 gpd or 16.2 lb per day/acre, and produces an effluent with a BOD of 8 ppm. The MPN count is reduced from 1.1 million to less than 300. A large oxidation pond system for treatment supplementary to primary sewage treatment is planned for Auckland, New Zealand (4). This will consist of 4 ponds, 4 ft deep and of a combined area of 1,390 acres. The city and its suburbs, area of 200 sq miles with an expected future population of 800,000, will contribute a flow of 33 mgd. Repeated recirculation of both the primary and the final effluent is expected to give a total detention period of 62 days.

In spite of the wide acceptance of oxidation lagoons, especially for small communities, the enthusiasm is not universal. Smith and Leibee (133) investigated the sanitary and financial advantages of sewage lagoons compared to standard treatment for the twin cities of Triumph and Monterey in Minnesota. In answer to questionnaires sent to bacteriologists and pathologists they found that there is danger of spreading disease, particularly sewage-borne virus diseases, by wind action or birds. They also found that due to turbidity of the ponds natural destruction of viruses is improbable. A study of construction costs showed that due to the high price of land a standard treatment plant would be only slightly more expensive than ponds. The operation of the ponds would cost less than that of an equally well performing standard plant, but not enough less to offset the possible danger of spread of disease.

Sewage Reuse

Heukelekian (72) has summarized his comprehensive report on practice and possibilities of using partially or completely treated sewage for crop irrigation in Israel. The report is based on a study of the volumes of sewage contributed by the various towns and cities, the crops to be irrigated, and the method and cost of transporting the sewage from the point of origin to the point of use. Special attention is given to the degree of treatment required for the particular application. The possibility of odor or esthetic nuisance during transportation and application is considered. The fertilizing value of the sewage, as well as possibility of soil damage due to chlorides, is investigated. Proposed reuse of treated sewage for industry and agriculture is reported from Haifa (5), Israel, where 90 per cent effective treatment is expected for a flow of 8 mgd. Primary settlement and trickling filters will be used, the effluent entering the Kishon River, from which it will be available for industry and unrestricted agriculture. According to Guyman (65), Coronado, California, planned to use the effluent of a proposed new treatment plant for irrigation of a golf course but this had to be abandoned due to a high chloride content of 350 to 1,200 mg/l. Benedickt (18) reports that Bremen, Germany, has to change its long-time method of sewage disposal. Due to the 6- to 9-ft tides of the Weser River,

which sweep all sewage out into the sea, the city can dispose of its sewage into that river except during late fall and winter. Then, the sewage is pumped onto a 9,300-acre area of meadows, divided into several individual large lagoons by low dykes. The water depth permitted is from 1.5 to 2 ft. Every few days, alternately, one of these lagoons is drained into the river. By that time the suspended solids have settled and fertilized the area for the coming growing season. No harm to health has as yet been traced to the system. In the near future, however, the growth of the city requires this area for industrial and residential expansion. Plans for activated sludge and high-rate filter treatment of the sewage are being developed.

The reuse of sewage in industry, as compared to its disposal by irrigation, is claiming more and well-deserved attention. Connell (39) distinguishes between natural reconditioning of used water by stream dilution or re-aeration, and planned reconditioning of the used water either by the first user of the water or the reuser. He gives examples of planned conditioning of sewage plant effluent as part of the treatment at the Amarillo and San Angelo, Texas, sewage treatment plants, as well as at the treatment plant going into operation at Odessa, Texas. He draws attention to the fact that silica and phosphates, heretofore seldom determined in routine sewage analysis, should be seriously considered, due to their effects in water used by industry. Allison (1) reports that a Corpus Christi, Texas, plant was designed to produce an effluent contracted for by an industry. Due to lack of funds and nonavailability of certain supplies, the design could not be carried out. Over the years, as funds were made available, these omissions were remedied, and the plant is now providing cooling water as called for in the contract. It has standard-rate filters, preceded by floceculation and sedimentation, and two roughing filters with their respective clarifiers. Part of the effluent, after chlorination at peak flow dosage, is returned to the incoming sewage. BOD reduction as high as 98 per cent is attained. According to Theroux (146) the Hyperion plant is also preparing for reuse of part of its effluent. It receives a high chloride content sewage from a certain area and a low chloride sewage from another. It was found possible to bring each of these two types to the treatment plant separately. The low chloride sewage will receive a high degree of treatment so as to fit it for industrial use, or to recharge it into the ground. The volume of this will eventually exceed 100 mgd. The high chloride sewage will receive partial treatment and be discharged into the ocean.

A comprehensive report on reuse of waste water has been released by the California State Water Pollution Control Board (31). Merz (100) has summarized this report and another review is available (8). Information was obtained through questionnaires sent to state agencies and by inspection visits to several plants. The report gives information on more than 150 industries that reclaim waste water and on 15 industries that utilize sewage plant effluents. Also included is a comprehensive coverage of agricultural utilization of sewage plant and lagoon effluents.

Gloyna (59) observed that in 94 counties in Texas, including 70 per cent of the population, more than one-half the waste water is secondary treated sewage. In 1954 this totaled approximately 130 bil gal. He emphasizes that since both the quality and the quantity of this water are of known reliability, its reclamation by enterprising organizations is to be expected. McGaughey (95) emphasizes that sewage reclamation should be thought of principally as supplying water for industry instead of for irri-

gation. He shows that the total sewage volume of California is only 8 per cent of the volume of water required for irrigation. He contrasts this with the potential value to industry of the volume of waste water, "thrown away," flowing from the State's two largest cities. He discusses the why and how of sewage effluent reclamation and illustrates with several instances in the southwest which represent well-planned projects on a scale sufficiently great to demonstrate the feasibility and practical economy of direct reuse of sewage effluents.

An interesting problem and a more interesting solution of this problem of sewage plant effluent reuse are reported from Chanute, Kansas (6). As the water supply of the city dwindled, and as the treatment plant produced a good effluent, the city was permitted by the State Board of Health to bring its effluent up the river to the waterworks intake. About 50 to 60 per cent of the effluent is to be so reused. Thomas (147) tells of the ownership or claim to water, whether from streams, or wells, aboveground or underground storage. Even the possible ownership of rain and run-off is discussed. Aside from the legal aspect of this ownership, it underlines the vastly increasing importance of water to human welfare.

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RADIOACTIVE WASTE DISPOSAL AT SEA

The U. S. Atomic Energy Commission has licensed several private firms to collect and dispose of atomic waste materials. These licenses cover by-product material (radioisotopes) and source material (uranium and thorium).

These licenses authorize the companies to gather waste materials from Atomic Energy Commission-licensed users and specify disposal at sea in at least 1,000 fathoms of water.

Waste materials are to be disposed of at sites selected with the U. S. Coast Guard which are outside normal shipping lanes. Materials are to be packaged in containers (usually 55-gal barrels) heavy enough to insure sinking to 1,000 fathoms.

The Atomic Energy Commission requires notification at least 10 days before each disposal, giving details of the disposal site location.

It is announced that at 1,000 fathoms the waste containers should not be affected by ocean currents. Also, there would not be any interference with fishing.

The containers are believed to resist deterioration for several years. When the radioactive materials are released, the rate is expected to be quite slow, and the dilution factor is estimated to prevent radiation levels in the harmful range.

Sewage Works

REDUCTION OF COLIFORM BACTERIA IN SEWAGE SLUDGE BY HALOGENS*

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Reduction of coliform bacteria to fewer than 100 per 100 ml in primary sewage sludge consistently has been attained under the following experimental conditions:

1. Limiting suspended solids to approximately 1 per cent by dilution of thicker sludge with supernatant sewage liquor.
2. Homogenizing the test samples in 2-l portions in a 1-gal blender at 13,000 rpm for 2 min.
3. Treating the homogenized samples with chlorine, bromine, or iodine-iodide solution so as to produce halogen residuals at the end of 2 hr greater than 10 mg/l equivalent of chlorine.
4. Gentle stirring during the 2-hr contact period.

These sludge halogenation experiments were initiated as an approach to studies of nitrogenous materials and suspended solids as limiting factors in disinfection of sewage and sewage sludge. The possibility of economic application of sludge disinfection with even the lowest cost halogen was at first given little consideration. But the fact that reduction of coliforms to fewer than 100 per 100 ml usually was effected at chlorine doses no higher than 5 g per 100 g of sludge solids, merits evaluation. This is particularly true if it can be demonstrated that the reduction in coliforms is accompanied by a significant reduction of pathogens.

In sludge chlorination studies by Tyler, Orlob, and Williams (1) a goal of 99 per cent reduction in coliforms was realized, through aid of dispersion of solids by 50- to 200-fold dilution plus homogenization. The required doses for primary and digested sludge were approximately 5 g per 100 g solids.

Chang and Morris (2) have reported evidence that elemental iodine is quite effective against several types of waterborne pathogens, including bacteria, amoebic cysts, cercariae, leptospirae, and viruses. They also found that nitrogenous impurities in water did not impair the germicidal action of iodine as much as that of chlorine. Chang, Baxter, and Eisner (3) have shown that elemental iodine is more germicidal than iodine in the form of the tri-iodide ion.

McKee (4), from studies on disinfection of settled sewage, reports that molecule for molecule, residual concentrations of chlorine, bromine, and elemental iodine are about equally effective in colicidal action. On the basis of chemically equivalent dosage chlorine was most effective, elemental

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TABLE I.—Rate of Reduction of Coliforms

Sample 6-A*			Sample 6-B†		
Time	Cl_2 Residual (mg/l)	Coliforms per 100 ml	Time	Cl_2 Residual (mg/l)	Coliforms per 100 ml
0	0	7.9×10^8	0	0	4.9×10^8
10 sec	158	130,000	25 sec	194	17,000
45 sec	123	45,000	45 sec	166	23,000
75 sec	118	45,000	75 sec	176	12,000
3 min	109	6,800	3 min	149	13,000
11 min	77	6,800	10 min	146	450
30 min	67	1,400	30 min	93	330
1 hr	51	780	1 hr	81	11
2 hr	36	2,300	2 hr	63	6.1
4 hr	18	39	4 hr	40	<1.8

* Suspended solids, 1.19 per cent; chlorine dose, 702 mg/l.
† Suspended solids, 1.18 per cent; chlorine dose, 674 mg/l.

iodine slightly less, and bromine only about one-half as effective.

Colicidal rates, percentage reduction, and reduction to stipulated low numbers are commonly used for measurement of effectiveness of sewage disinfection. Consideration of two chlorination tests on homogenized sludge illustrates why reduction of coliforms to fewer than 100 per 100 ml may be a realistic indication of disinfection effectiveness in such complex concentrated material. These tests were made on two comparable sludge samples in an attempt to follow chlorine demand and colicidal rates. Results are listed in Table I and semilog plottings with freehand curves of apparent best fit are presented in Figure 1.

Within the first minute, chlorine demand and colicidal action proceed at immeasurable rates. The high initial rate of kill is due to a high population of most susceptible organisms exposed to high concentrations of the most active forms of available chlorine. The fraction remaining, in the order of 1×10^{-4} to 1×10^{-5}, still represents significant numbers. These are no doubt more resistant and less exposed, but still sufficiently susceptible and exposed to succumb to the lower and still decreasing concentrations of less germicidal forms of available chlorine. Total kill is closely approached within 2 hr. It is in this phase of measurable rates of chlorine demand and colicidal action that most information can be obtained on suspended solids and nitrogenous materials as influencing factors in disinfection of sewage and sludge.

Such studies are in progress to observe correlations of colicidal results with halogen doses and residuals imposed, with nitrogenous components and with degree of dispersion of suspended solids. The observations reported in this paper are limited primarily to the 2-hr residuals found necessary to approach a total kill of coliform bacteria in primary sludge when the suspended solids are dispersed by a 3- to 10-fold dilution of thick sludge, plus blending action of high-speed mechanical stirring.

Experimental Procedures

Sludge Sources

Very fresh sludge was procured by 1-hr settling of Galveston, Tex., sewage in 20-gal cans just prior to time of use in halogenation experiments. Slightly septic sludge was obtained from Lamarque, Tex., primary sedimentation tanks at and midway between the regular 4-hr sludge withdrawal intervals. The Galveston sewage usually contained 5 to 20 per cent brewery

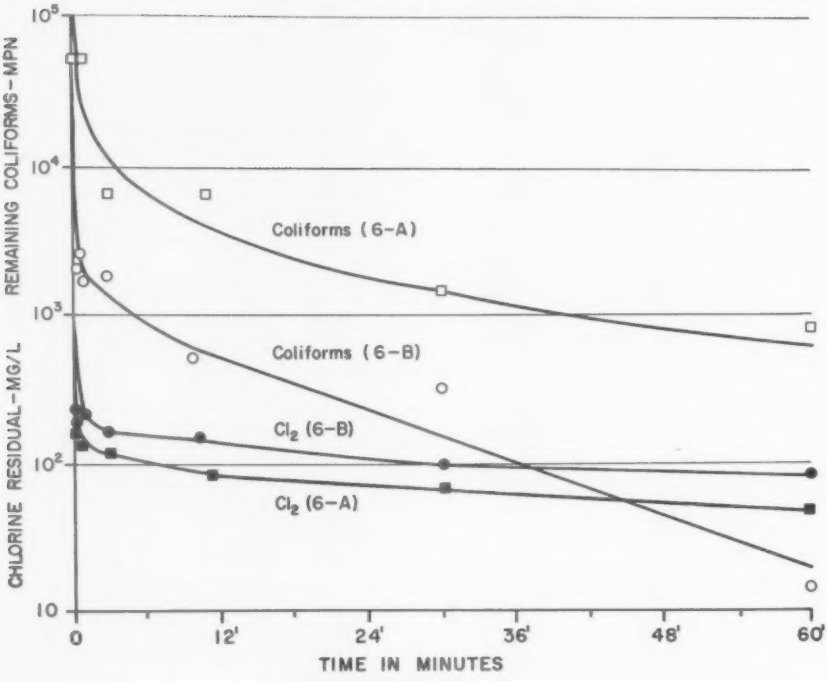

FIGURE 1.—Colicidal rate.

wastes (on BOD basis). The Lamarque sewage was 100 per cent domestic.

Preparation of Test Samples

At the time of collection of a sludge sample it was thinned to within 30 to 40 per cent of the desired suspended solids content by diluting with liquor supernatant to the thicker sludge. The thinned sample was homogenized in 2-l portions in a 1-gal Waring Blendor at 13,000 rpm for 2 min. The homogenized sludge was divided into the desired number of equal portions, usually 700 ml. Control samples were diluted to 1 liter with Galveston tap water. Measured volumes of tap water were added to other test portions, such that the final volumes would be 1 liter after the desired halogen doses were added.

Composition of Test Samples

Bacterial and chemical analyses were initiated on control specimens at the time of setting up a series of test portions. Analyses were made on dehalogenated test portions at significant intervals during and at the end of an experiment. The ranges of results of chemical tests on control specimens are given in Table II.

Wide variations in suspended solids were deliberately included. The variations in total nitrogen were primarily due to variations in suspended solids content. Variations in other components were primarily due to variations in composition of supernatant sewage and condition of the sludge.

Halogen Dosage Water

Halogen dosage solutions were prepared in Galveston tap water. Concentrations were in the range of 50 to

TABLE II.—Characteristics of Sludge Test Samples

Item	Galveston, Tex.[1]	Lamarque, Tex.[2]
Number of test samples	12	32
Suspended solids (%)	0.44 to 1.66	0.26 to 2.29
Vol. susp. solids (% of ss)	72 to 83	50 to 85
pH	6.7 to 7.4	6.8 to 7.5
Alkalinity (mg/l)	480 to 980	460 to 840
Chloride (mg/l)	510 to 910	230 to 560
Ammonia nitrogen (mg/l)	18 to 48	7 to 47
Albuminoid nitrogen (mg/l)	28 to 69	20 to 77
Total nitrogen (mg/l)	150 to 440	100 to 440
Sulfide (mg/l)	——— ———	8 to 55

[1] Laboratory settled.
[2] From primary tank.

100 me/l (2,000 to 3,500 mg/l of equivalent chlorine). Due to the high doses required, the iodine solutions were of necessity iodine-iodide solutions such that a major portion of the iodine was in the form of the tri-iodide ion (I_3^-) instead of elemental iodine. Solutions used were made approximately 0.4 M to insure that the iodine would be more than 95 per cent in the form I_3^-. This was based on consideration of the equilibrium constant reported by Jones and Kaplan (5) for the reaction of iodine (I_2) and iodide (I^-).

$$I_2 + I^- \rightleftarrows I_3^- \quad \ldots\ldots (1)$$

$$\frac{[I_2][I^-]}{[I_3^-]} = K = 1.4 \times 10^{-3} \quad \text{(at 25°C)} \ldots (2)$$

For 0.4 M I^-,

$$\frac{[I_2]}{[I_3^-]} = \frac{K}{[I^-]} = \frac{1.4 \times 10^{-3}}{0.4} = 0.0035 \ldots\ldots (3)$$

A ten-fold dilution of 0.4 M iodide at time of dosage would theoretically leave 96.5 per cent of the available iodine in the form of the tri-iodide ion. Solutions of sufficient available iodine concentration have been prepared that were only 0.1 M with respect to I^-. Even with this iodine solution the theoretical maximum proportion of available elemental iodine at time of dosage would be no greater than 14 per cent.

Dosage and Contact Period Conditions

Halogen dosage water was added rapidly, at uniform rates from sample to sample and experiment to experiment. Samples were stirred vigorously during dosage. Throughout halogen contact periods samples were stirred at a uniform rate just sufficient to prevent subsidence of suspended solids. A Phipps and Bird 6-unit laboratory mixer was used, operating at 60 rpm. Some experiments were made in which samples were stirred only at sampling times; that is, at 10, 30, 60, and 120 min. In such tests, slightly higher 2-hr residuals were observed. Coliciadal results, however, were approximately the same as for comparable samples and dosages when continuous stirring was applied (see footnote, Table III).

Range of Suspended Solids Content

Tyler *et al.* (1) made 50- to 200-fold dilutions of primary and digested sludge prior to homogenization and chlorination. For a 5 per cent sludge, a 50-fold dilution would leave only 0.1 per cent suspended solids. For the experiments herein reported it was decided to start at approximately 0.2 per cent suspended solids and progress to

higher solids content. Most recent experiments have been at suspended solids slightly higher than 1 per cent after addition of halogen dosage. Liquor immediately supernatant to thicker sludge has been used for dilution in order to have soluble components approximately the same as that of the undiluted sludge.

Homogenization Period

The goal in dispersion of suspended solids by blending action was to reduce particle size to effect maximum exposure of bacteria and yet not kill appreciable numbers through prolonged high-speed agitation. The largest available laboratory blender was obtained. This was a 1-gal Waring Blendor having three rated speeds of 13,000, 16,000, and 18,500 rpm. The lowest rate was selected as standard operating speed, and a 2-l portion was chosen as standard volume for homogenization. The selection of 2 min as the standard homogenization period was based on the following experience:

1. Physical and microscopic examination of samples indicated no significant disintegration benefits by homogenization time in excess of approximately 2 min.
2. Homogenization of samples for periods up to 4 min produced no demonstrable colicidal effect attributable to the high mechanical agitation.
3. Chlorination of non-homogenized samples gave an apparent high colicidal effect. But when such samples were homogenized after dechlorination, much higher numbers of remaining coliforms invariably were demonstrated to be present.
4. Such post-homogenization of samples that had been pre-homogenized for at least 2 min gave little or no significant increase in apparent numbers of remaining coliforms.

Halogen Contact Period

The results of repeated experiments to observe colicidal rates readily demonstrated that an approach to a total kill of coliforms would require a halogen contact time of at least 1 hr for any feasible combination of experimental conditions (see Table I and Figure 1). Even though colicidal action frequently was demonstrable through 4-hr periods, it appeared that a 2-hr period was most applicable for observation of reduction of coliforms to below 100 per 100 ml. It was recognized that a 2-hr halogen residual *per se* was not a sole criterion for indication of colicidal effectiveness; therefore, halogen residuals were observed at as frequent intervals as seemed feasible (10 min, 1 hr, and 2 hr).

Procedure for Halogen Residuals

The "Standard Methods" (6) starch-iodide method for measuring chlorine residual in sewage was used for measuring halogen residuals. The high residuals and high suspended solids of samples required a 5- to 20-fold dilution of test portions. The dilutions were made in portions of distilled water containing the measured volumes of acetate buffer, potassium iodide, and standard thiosulfate. It is believed that the procedure measures with sufficient accuracy the effective halogen residuals present.

Procedure for Coliform Bacteria

The "Standard Methods" (6) multiple dilution procedure for estimating most probable numbers (MPN) of coliform bacteria in water was used for all tests. Lactose broth was used for the presumptive tests, planting five tubes for each dilution. Brilliant green lactose bile broth was used for confirmation tests. The procedure leaves much to be desired, but it is believed that most of the results fall well within the 13-fold range for 95 per cent confidence limits recently reported by Woodward (7). The high suspended solids content, combined with the low coliform numbers at-

tained, precluded the possibility of using membrane filter procedures.

Results

Chlorination Tests—Suspended Solids 0.26 to 0.97 Per Cent

Fourteen samples have been used in chlorination experiments where the following conditions were imposed:

1. Homogenization of samples for 2 min.
2. Suspended solids in final test portions limited to 1 per cent or less.
3. Chlorine doses sufficient to obtain 2-hr residuals greater than approximately 10 mg/l.
4. Continuous gentle stirring during the 2-hr contact period.

Results of these experiments, including 35 individual chlorination tests, are presented in Tables III and IV. For nine of the samples, at least one of the chlorine doses was such that the 2-hr residual appeared to be very close to the minimum required to reduce coliforms to below 100 per 100 ml. The range of these residuals was 8 to 20 and the average 14 mg/l. One 2-hr residual of 17 mg/l, within the 8 to 20 range, resulted in an MPN reduction to 110 per 100 ml (see Table IV, ss at 0.96 per cent). In 17 other tests the 2-hr residuals were appreciably above the apparent 8- to 20-mg/l minimum required range. The coliform reduction, as indicated by the MPN determination, was consistently well below 100 per 100 ml level. In a few instances the MPN fell to below 1 per 100 ml. The ranges and averages of chlorine doses and residuals and other pertinent data are summarized in Table V. The required chlorine

TABLE III.—Reduction of Coliforms in Sewage Sludge: Suspended Solids, 0.26 to 0.63 Per Cent

Susp. Solids (%)	Chlorine Dose (mg/l)	Chlorine Residual (mg/l)			Coliforms (MPN/100 ml)	
		10 Min	1 Hr	2 Hr	Original	At 2 Hr
0.26	234	46	28	24	1.7×10^8	0.78
0.26	312	42	34	30	1.7×10^8	3.4
0.44	81	0	0	0	1.3×10^8	$>2.4 \times 10^6$
0.44	161	6	4	0	1.3×10^8	540
0.44	242	36	20	10	1.3×10^8	33
0.44	320	64	48	28	1.3×10^8	4
0.44	400	100	75	60	1.3×10^8	2.3
0.44	480	95	65	50	1.3×10^8	0.7
0.54	126	2	1	0	7.1×10^8	>2,400
0.54	168	16	4	3	7.1×10^8	240
0.54	252	42	22	13	7.1×10^8	23
0.54	336	82	54	35	7.1×10^8	4.9
0.54	420	100	80	60	7.1×10^8	7.9
0.56	210	75	50	20	5.4×10^8	45
0.56	210	90	60	25	5.4×10^8	40
0.60	230	40	28	15	2.3×10^8	40
0.63	317	78	54	37	7.9×10^8	13
0.63	317	78	56	39	7.9×10^8	7.9
0.63*	317	80	64	51*	7.9×10^8	3.0
0.63*	317	78	66	50*	7.9×10^8	4.9

* Not stirred during contact period except at 10 min, 1 hr, and 2 hr.

TABLE IV.—Reduction of Coliforms in Sewage Sludge: Suspended Solids, 0.72 to 0.97 Per Cent

Susp. Solids (%)	Chlorine Dose (mg/l)	Chlorine Residual (mg/l)			Coliforms (MPN/100 ml)	
		10 Min	1 Hr	2 Hr	Original	At 2 Hr
0.72	208	33	6	2	2.4×10^5	540
0.72	416	116	94	76	2.4×10^5	2
0.73	235	46	21	12	11×10^5	45
0.73	235	41	20	12	11×10^5	45
0.73	326	101	60	43	11×10^5	5.6
0.73	326	98	62	43	11×10^5	5.6
0.74	338	73	46	35	0.35×10^5	23
0.74	268	38	17	8	3.3×10^5	24
0.74	447	79	60	42	3.3×10^5	4.9
0.77	347	59	26	18	4.9×10^5	49
0.93	434	52	32	19	4.9×10^5	33
0.96	435	41	25	17	7×10^5	110
0.96	435	42	24	14	7×10^5	32
0.96	675	78	62	49	7×10^5	11
0.96	675	81	56	48	7×10^5	4
0.97	388	76	54	34	0.5×10^5	0.7
0.97	466	67	48	29	0.5×10^5	0.2

doses, on mg/l basis, at first thought seem to be extremely high, but when considered on the basis of g/100 g or lb/100 lb of suspended solids, do not appear too unrealistic. The actual numbers of coliforms remaining are very small, but may be still significant from the standpoint of disinfection. The fractions of coliforms remaining are extremely small.

Chlorination Tests—Suspended Solids Greater Than 1 Per Cent

Results of chlorination tests on samples containing suspended solids higher than 1 per cent are given in Tables VI to IX. The homogenization time, 2 min, and the gentle stirring through the 2-hr contact period were the same as for samples of lower solids content.

TABLE V.—Reduction of Coliforms in Sewage Sludge by Chlorine: Suspended Solids, 0.26 to 0.97 Per Cent

Item	Min Effective 2-Hr Residuals for MPN to Below 100/100 ml[1]		MPN to Below 100/100 ml[2]	
	Range	Average	Range	Average
Suspended solids (%)	0.44 to 0.96	0.7	0.26 to 0.97	0.7
Chlorine dose (mg/l)	210 to 435	300	210 to 675	355
Chlorine dose (g/100 g ss)	3.2 to 5.5	4.3	3.2 to 7.0	5.1
Chlorine residual (mg/l)	8 to 20	14	8 to 76	32
MPN remaining	24 to 45	36	0.2 to 49	17.5
Fraction *coli* remaining	$(3.2 \text{ to } 25)10^{-3}$	9.5×10^{-3}	$(0.4 \text{ to } 65)10^{-5}$	4.4×10^{-4}

[1] 9 samples.
[2] 14 samples, 29 tests.

TABLE VI.—Reduction of Coliforms in Sewage Sludge: Suspended Solids Higher than 1 Per Cent

Susp. Solids (%)	Chlorine Dose (mg/l)	Chlorine Residual (mg/l)			Coliforms (MPN/100 ml)	
		10 Min	1 Hr	2 Hr	Original	At 2 Hr
1.19	360	29	19	1.2	22×10^8	230
1.19	360	31	19	1.8	22×10^8	130
1.19	440	57	33	17	22×10^8	54
1.19	440	52	31	17	22×10^8	160
1.28	484	35*	26	19	2.3×10^8	17,000
1.28	623	55*	42	33	2.3×10^8	3,300
1.28	761	79*	58	44	2.3×10^8	28
1.54	330	19	5	0	9.2×10^8	920,000
1.54	440	25	11	6	9.2×10^8	160,000
1.54	550	38	25	18	9.2×10^8	2,200
1.54	660	63	40	29	9.2×10^8	540
1.54	770	71	51	42	9.2×10^8	470
1.54	880	94	69	52	9.2×10^8	27
1.66	501	38	17	7	0.45×10^8	7,900
1.66	501	36	14	9	0.45×10^8	4,900
1.66	668	62	43	28	0.45×10^8	3,300
1.66	668	59	38	30	0.45×10^8	700

* Chlorine residual at 30 min.

There is evidence that, with increasing suspended solids, progressively higher 2-hr residuals were required to reduce coliforms to below 100 per 100 ml. The observed minimum residuals effecting this reduction in six samples (suspended solids, 1.03 to 1.54 per cent) ranged from 16 to 52 and averaged 29 mg/l. The doses required to effect these residuals ranged from 446 to 880 and averaged 576 mg/l. On the basis of g/100 g of suspended solids the doses varied from 3.7 to 5.7 while averaging 4.6 g. These ranges and averages are summarized in Table VII.

Tests with Bromine and Iodine

The results of experiments in which colicidal effectiveness of bromine and iodine was compared with that of chlorine are reported in Tables VIII and IX. Summaries of observed minimum residuals resulting in reduction of coliforms to below 100 per 100 ml are

TABLE VII.—Reduction of Coliforms in Sewage Sludge by Chlorine[1] (6 Samples; Suspended Solids, 1.03 to 1.54 Per Cent)

Susp. Solids (%)	Orig. (MPN)	Chlorine Dose		Cl_2 Residual (mg/l)	MPN at 2 Hr	Fraction MPN Remaining
		(mg/l)	(g/100 g ss)			
1.03	2.3×10^8	483	4.7	27	7.8	3.4×10^{-8}
1.12	1.7×10^8	446	4.0	16	70	41×10^{-8}
1.13	4.9×10^8	446	3.9	17	79	16×10^{-8}
1.19	22×10^8	440	3.7	17	54	2.5×10^{-8}
1.28	2.3×10^8	761	5.9	44	28	12×10^{-8}
1.54	9.2×10^8	880	5.7	52	27	2.9×10^{-8}
Avg 1.22	7.2×10^8	576	4.7	29	44	12×10^{-8}

[1] Minimum observed 2-hr residuals for MPN to below 100 per 100 ml.

TABLE VIII.—Reduction of Coliforms in Sewage Sludge: Comparison of Chlorine and Bromine

Susp. Solids (%)	Coliforms (MPN)	Chlorine (mg/l)				MPN	Bromine (mg/l)*				MPN
		Dose	Residuals				Dose	Residuals			
			10 Min	1 Hr	2 Hr			10 Min	1 Hr	2 Hr	
0.74	3.3×10^8	268	38	17	8	24	269	4	0	0	7,800
0.74	3.3×10^8	447	79	60	42	4.9	448	21	4	2	2,700
0.74	3.3×10^8	—	—	—	—	—	672	90	33	13	0.2
1.03†	2.3×10^8	289	27	8	3	330	600	16	3	0	16,000
1.03	2.3×10^8	386	63	30	18	170	750	22	7	1	180
1.03	2.3×10^8	483	84	47	27	7.8	900	43	11	5	<1.8
1.03	0.8×10^8	—	—	—	—	—	780	27	9	4	430
1.03	0.8×10^8	—	—	—	—	—	960	74	18	9	11
1.03	0.8×10^8	—	—	—	—	—	1,080	123	34	14	<1.8
1.13	1.7×10^8	323	34	18	10	170	512	8	4	0	70,000
1.13	1.7×10^8	539	68	48	42	79	849	46	16	10	6.1
1.24†	7.9×10^8	302	6	2	0	—	624	6	2	0	—
1.24	7.9×10^8	403	16	—	2	—	832	10	4	0	—
1.24	7.9×10^8	504	24	16	12	7,900	1,040	14	9	4	110

* In equivalent chlorine.
† See also Table IX.

TABLE IX.—Reduction of Coliforms in Sewage Sludge: Comparison of Chlorine and Iodine

Susp. Solids (%)	Coliforms (MPN)	Chlorine (mg/l)				MPN at 2 Hr	Iodine (mg/l)*				MPN at 2 Hr
		Dose	Residuals				Dose	Residuals			
			10 Min	1 Hr	2 Hr			10 Min	1 Hr	2 Hr	
0.97	0.49×10^8	388	76	54	34	0.7	226	60	34	9	7.9
0.97	0.49×10^8	466	67	48	29	<0.2	302	107	83	54	0.9
1.03†	2.3×10^8	289	27	8	3	330	204	36	7	0	340
1.03	2.3×10^8	386	63	30	18	170	271	81	30	14	240
1.03	2.3×10^8	483	84	47	27	7.8	337	137	70	35	14
1.12	1.7×10^8	397	50	19	10	330	276	60	10	6	49
1.12	1.7×10^8	446	52	30	16	70	318	81	31	12	46
1.12	1.7×10^8	496	54	52	35	11	341	110	59	49	33
1.13	4.9×10^8	397	44	23	9	170	293	78	32	12	21
1.13	4.9×10^8	446	57	31	17	79	325	101	46	19	26
1.13	4.9×10^8	496	68	39	20	110	358	120	68	33	33
1.24†	7.9×10^8	403	16	—	2	—	284	44	28	10	260
1.24	7.9×10^8	504	24	16	12	7,900	355	88	70	46	17
1.92	2.4×10^8	340	21	12	0	35,000	192	12	0	0	$>2.4 \times 10^5$
1.92	2.4×10^8	425	53	26	11	35,000	260	43	10	1	2,300

* In equivalent chlorine.
† See also Table VIII.

TABLE X.—Reduction of Coliforms in Sewage Sludge by Bromine and Iodine: Comparison with Chlorine

(Minimum Observed Doses and Residuals for MPN to Below 100 per 100 ml)

Susp. Solids (%)	Chlorine (mg/l)		MPN at 2 Hr	Bromine (mg/l)[1]		MPN at 2 Hr	Dose Ratio Br_2/Cl_2
	Dose	Residual 2 Hr		Dose	Residual 2 Hr		
0.74	268	8	24	672	13	0.2	2.5
1.03	483	27	7.8	900	5	1.8	1.9
1.03	483	27	7.8	960	9	11	2
1.13	539	42	79	849	10	6.1	1.6
1.24	504	12	(7,900)	1,040	4	(110)	2.1
Susp. Solids (%)	Chlorine (mg/l)		MPN at 2 Hr	Iodine (mg/l)[1]		MPN at 2 Hr	Dose Ratio I_2/Cl_2
	Dose	Residual 2 Hr		Dose	Residual 2 Hr		
0.97	388	34	0.7	226	9	7.9	0.56
1.03	483	27	7.8	337	35	14	0.7
1.12	446	16	70	276	6	49	0.62
1.13	446	17	79	293	12	21	0.66
1.24	504	12	(7,900)	355	47	17	0.70

[1] In equivalent chlorine.

presented in Table X. All doses and residuals are expressed in chemically equivalent chlorine. The results of this limited number of comparisons indicate that chemically equivalent residuals of chlorine and iodine have approximately the same colicidal effect. On the same basis there were indications that bromine had a higher effect. The required doses of iodine were approximately two-thirds and those of bromine approximately twice the doses required for chlorine.

Discussion

Colicidal action in these sludge halogenation experiments was no doubt augmented by lowering of pH. The buffering action of the high alkalinity and suspended solids prevented this from being a major factor, except with the high required doses of bromine.

In five of the chlorination tests pH values fell to below 5.0 (range 4.3 to 4.9) and in five others to the range of 5.0 to 5.4. Most of these were with samples receiving doses in excess of the minimum required to reduce coliforms to below 100 per 100 ml. Aftergrowth of coliforms resulted in such samples when they were dechlorinated and seeded with fresh sewage. The terminal pH values ranged from 6.0 to 7.2 for observed minimum effective doses and residuals in tests at suspended solids lower than 1 per cent (Table V). The terminal pH range was 6.0 to 6.3 for effective iodine doses and residuals at suspended solids from 0.97 to 1.24 per cent (Table IX).

The required bromine doses reduced pH to such low values that satisfactory comparisons cannot be made of the effective bromine residuals with the effective chlorine and iodine residuals attained at higher pH values. Bittenbender *et al.* (8) and Rahn (9) have reported colicidal action due to acidity alone at pH values below 3.0. They also have shown that lowered pH values augment action of many bactericides, but are not the major factor at a pH above approximately 3.0.

For bromine doses and residuals which reduced coliforms to below 100 per 100 ml, pH values fell below 4.0.

In one test at suspended solids of 1.13 per cent and bromine dose of 849 mg/l (Table VIII), the pH value declined to 2.6. Other bromine doses reduced pH values below 4.0 without producing a measurable 2-hr bromine residual. In such tests, coliforms were not reduced to a level as low as 100 per 100 ml.

The finally effective colicidal action of halogen doses and residuals imposed is attributed primarily to dispersion of solids. It is reasonable to assume that if solids are disintegrated sufficiently to expose individually all organisms, the principal if not the only limiting factor to total kill is the specific resistance of the organisms to germicidal agents present. Experimental failure to attain total kill was probably due in most instances to the presence of particles still large enough to house and protect bacteria. Increased higher 2-hr residuals were required for increased solids content of samples. This is attributed in part to less efficiency in homogenization in the samples of higher solids concentration. It also may be due to tying up of more of the available halogen in less bactericidal forms by the increased mass of nitrogenous material.

Summary

Reduction of coliform bacteria in primary sewage sludge to most probable numbers below 100 per 100 ml consistently has been attained under the following experimental conditions:

1. Limiting suspended solids to 1 per cent or less in final chlorinated portions, by diluting with liquor immediately supernatant to thicker sludge.

2. Homogenizing the diluted samples in 2-l portions for 2 min in a 1-gal blender at 13,000 rpm.

3. Adding sufficient chlorine water to the homogenized samples to obtain 2-hr residuals in the range of 10 to 20 mg/l.

4. Stirring the chlorinated samples during the 2-hr contact period at a rate barely sufficient to prevent subsidence of solids.

Minimum doses required for very fresh to slightly septic sludge, in samples having from 0.44 to 0.97 per cent suspended solids, ranged from 210 to 435 and averaged 300 mg/l. On a g per 100 g suspended solids basis, the required doses averaged 4.3 g, with total variation from 3.2 to 5.5.

Increased 2-hr residuals and mg/l doses were required with increased suspended solids content. For samples having 1.03 to 1.54 per cent solids, required residuals varied from 16 to 52 and averaged 29 mg/l, required doses ranged from 446 to 880 and averaged 576 mg/l, and on g per 100 g suspended solids basis the required doses averaged 4.7 g from limits of 3.7 to 5.7.

In comparable halogenation experiments using bromine water and iodine-iodide solution, results obtained indicated that on chemical equivalent basis bromine residuals had greater colicidal activity than the chlorine or iodine residuals. Chemically equivalent chlorine and iodine residuals had approximately the same colicidal activity.

On chemical equivalent basis the required effective bromine doses were approximately twice and the required iodine doses were two-thirds those required for chlorine.

Acknowledgment

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WASTE–WATER REUSE PREDICTIONS

In a 2-yr study of the potential for water reuse in eastern Texas, waste-water quantities were estimated for the next 50-yr period. At present, about 29 per cent of the total water demand of the project area, or about 130 bil gal, finally appear as secondary treated sewage. By 2010 this proportion is expected to decline to about 22 per cent; however, by that time total water demands will have increased to almost five times the 1954 volume.

The following shows the estimated waste-water production by major industries in the area of study for the period 1954 to 2010:

Industry	Quantity of Waste Water (bil gal/yr)		
	1954	1975	2010
Mining	9.34	15.41	14.32
Primary metal products	3.72	11.39	34.33
Transportation equipment	2.02	4.56	12.88
Stone, clay, and glass products	0.91	1.79	3.29
Food and kindred products	8.45	14.46	23.45
Textile products	0.48	1.05	2.14
Paper and allied products	15.32	41.96	75.92
Chemicals and allied products	46.42	176.10	452.83
Petroleum and coal products	38.55	70.40	75.27
Others	17.01	30.25	49.79
Total	142.22	367.37	744.22

WASTE STABILIZATION PONDS

II. FIELD PRACTICES*

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Due to pioneer efforts in the development of waste stabilization ponds a wealth of data has been obtained by the Texas State Department of Health from various installations in operation throughout the State of Texas. From this background data, classification and compilation were made to make a statistical analysis.

Scope of Study

A list of communities known to utilize waste stabilization ponds for all or part of their sewage treatment was provided by the Water Pollution Control Division of the Texas State Health Department. Parameters relative to waste stabilization ponds were selected for:

1. Their importance in measuring the degree of waste treatment accomplished.
2. Their relationship to nuisance and aesthetic values.
3. Their relationships to community size and waste characteristics.
4. Their significance in developing design criteria.

Tables containing a list of communities selected for study and 48 different column headings were constructed. The data compiled in these tables were obtained from three sources: (a) the correspondence and municipal status files of the Texas State Health Department's Water Pollution Control Division; (b) a waste stabilization pond field study made in 1955 under U. S. Public Health Service sponsorship; and (c) pond or lagoon studies made by Texas Health Department personnel during the past few years.

At least 95 per cent of the data pertinent to the chosen parameters was selected and tabulated. Most of these data originated within the past few years and utilization of data antedating 1950 was unnecessary in all but a few cases.

Analysis Procedures

Each column of tabulated data was subjected to a statistical analysis, or if the parameter involved did not lend itself to numerical expression, the data were simply separated into categories. Table I includes the statistical summary for these data. The values reported for summation (Σ), number of observations (N), crude arithmetic mean (M), and maximum and minimum were obtained by simple arithmetic and direct observation. The remaining values for each parameter, however, required the construction of a frequency distribution and plotting of frequency distribution summation values on arithmetic probability and logarithmic probability paper. The mode (M_o), was then selected and the median (M_d) calculated from the frequency distribution table. From the two summation plots of the frequency

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distribution, the distribution was designated as either arithmetically normal or geometrically normal and the appropriate mean (M_a) or (M_g) and its corresponding standard deviation (σ_a) or (σ_g) were obtained graphically.

In reviewing the statistical summary it should be borne in mind that in an arithmetically normal frequency distribution the arithmetic mean and median coincide. In a geometrically normal frequency distribution the geometric mean and median coincide. Just as the ranges $M_a \pm \sigma_a$, $M_a \pm 2\sigma_a$, and $M_a \pm 3\sigma_a$ of an arithmetically normal curve include 68.2 per cent, 95.5 per cent, and 99.7 percent, respectively, of all values; similarly, the ranges $M_g \times\div \sigma_g$, $M_g \times\div \sigma_g^2$, and $M_g \times\div \sigma_g^3$ of a geometrically normal curve will include the same percentages, i.e., 68.2, 95.5, and 99.7 per cent. In addition, the geometric standard deviation inherently incorporates the concept of the coefficient of variation because it is a ratio to the geometric mean.

As a note of caution, the statistical analysis for each column heading is based upon random observations reported from waste stabilization ponds actually in operation. As such, the average figures reported represent the central tendency of that which occurs in practice throughout a certain geographical area and not a recommendation of these figures as optimum values.

Results

The results of this study of waste stabilization ponds in Texas are presented numerically in Tables II to VII. Raw data tabulations from which these results were obtained may be found in a report prepared for the Atomic Energy Commission (1).

Discussion

Population and Sewage Characteristics

The waste stabilization ponds included in this study were designed to serve populations ranging from 500 to 56,000 people. However, one undesigned pond, actually a lake near San Antonio, is occasionally used as an auxiliary treatment device to serve more than 500,000 people. The population of the average community may be projected from the 1950 figure to the present time as about 2,700 people whereas the average population served is estimated currently as 2,200. The design population, relatively unaffected by the time lapse between the origination of the data and its utilization in this study, may be taken directly as 2,810, the M_g value.

Sewage flow, based upon population served, averaged 80 gpd/cap and in one-half the cases reported this waste water contained industrial wastes. Poultry packing plants were the main industrial waste contributors in these small communities. It should also be noted that in 174 of the 182 communities reporting on pretreatment, their waste stabilization ponds were used as secondary or even tertiary treatment devices; only 4.4 per cent of the installations used ponds for primary treatment. Of a wide variety of pretreatment devices employed, Imhoff tanks were by far the most common.

Pond Sizes, Arrangements, and Recirculation

The data relative to the number of pond cells per installation, pond dimensions, provisions for recirculation, connection of ponds in series or parallel, and detention period may be taken at face value.

Influent and Effluent Analyses

The chemical and physical analyses reported in statistical form were derived from raw data obtained in accordance with standard sampling and analytical techniques. The analytical techniques may be considered quite uniform but the sampling techniques varied with the exigencies of the situation. Some of the results were obtained from grab samples while others

TABLE I.—Statistical Summary of Waste Stabilization Ponds in Texas

Statistical Entity[1]	1950 Population[2]	Design Population	Population Served	Inauguration Date	Influent (mgd)	No. of Pond Cells	Total Area (Acres)	Pond Dimensions			BOD (mg/l)		Suspended Solids (mg/l)		Phenolphthalein Alk. (mg/l)		Total Alk. (mg/l)		Statistical Entity[1]
								Length (ft)	Width (ft)	Depth (ft)	In	Out	In	Out	In	Out	In	Out	
Σ	1,259,513	692,354	1,004,709	325,083	103.12	360	1,910.18	18,683	6,257	364	10,215	1,616	8,110	4,640	0	1,160	18,172	9,492	Σ
N	188	121	119	167	114	162	151	35	35	115	63	38	56	37	43	28	44	30	N
Max	408,442	56,000	500,000	1,954	54.0	20	850	2,750	600	10	2,110	403	424	684	0	360	705	880	Max
Min	175	500	300	1,902	0.017	1	0.04	100	300	2	11	1	22	10	0	0	117	34	Min
M_a	1,500⁺	1,000⁺	1,500⁺	1,950⁺	0.05⁺	1⁺	2⁺	300⁻	100⁺	3⁻	125⁻	10⁺	125	90	—	0⁺	350⁺	350⁻	M_a
M_d	2,366	2,771	1,992	1,950.4	0.156	1.39	4.19	285	140	2.96	123	23.6	129	91	—	16.7	409	320	M_d
C_{fd}	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Arith.	Geom.	Geom.	Arith.	—	Geom.	Arith.	Arith.	C_{fd}
M_a	—	—	—	—	—	—	—	—	—	—	125	—	—	92.0	—	—	415	316	M_a
M_g	2,350	2,810	1,960	1,950.4	0.157	1.56	4.18	300	146	2.96	—	25.2	124	—	—	19.8	—	—	M_g
$\sigma_a \pm$	—	—	—	—	—	—	—	—	—	—	85	—	—	47	—	—	145	147	$\sigma_a \pm$
σ_g^x	2.82	2.51	2.80	1.00085	4.33	2.29	2.91	2.19	2.18	1.42	—	2.06	1.79	—	—	4.90	—	—	σ_g^x
M	6,700	5,722	8,443	1,948.4	0.905	2.22	12.7	534	179	3.17	162	42.5	145	125	0	4.14	413	316	M

TABLE I.—Statistical Summary of Waste Stabilzation Ponds in Texas (cont.)

Statistical Entity[1]	pH		Chlorides (mg/l)		BOD Loading (lb/ac/d)	BOD Remaining In Effluent (%)	Average dry-bulb temperature (°F)[2]			Avg Wind Speed[4] (mph)	Possible Sunshine[4] (%)	Sky Cover[4] (%)	Annual Evap. Minus Precip.[5] (in.)	Land Irrigated with Effl. (acres)	Detention Period (days)	Statistical Entity[1]
	In	Out	In	Out			Annual	Max	Min							
Σ	368.3	297.2	7,023	5,272	5,621	1,225	1,942	2,744	1,110	286	1,126	106.2	728	4,267	1,213.5	Σ
N	50	36	43	29	34	35	29	29	29	27	17	22	29	43	33	N
Max	8.2	9.9	632	838	2,280	127	74	100	52	13	76	5.7	48	1,300	196	Max
Min	5.8	7.0	21	57	2	1	57	85	22	8	61	4.0	3	10	1	Min
M_o	7.4$^+$	8.4$^-$	75$^+$	75$^+$	30$^+$	10$^+$	66$^+$	96$^-$	37.5$^+$	11$^-$	67$^-$	4.7$^+$	17.5$^+$	25$^+$	25$^+$	M_o
M_d	7.42	8.33	119	121	32.5	24.3	66.9	95.3	38.5	10.9	67.0	4.78	22.9	41.3	26.9	M_d
C_{fd}	Arith.	Arith.	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Geom.	Arith.	Geom.	Geom.	Arith.	Geom.	Geom.	C_{fd}
M_a	7.43	8.33	—	—	—	—	—	—	—	10.8	—	—	25.9	—	—	M_a
M_g	—	—	120	132	34.2	23.8	67.0	94.7	38.6	—	66.8	4.80	—	44.0	26.6	M_g
$\sigma_a\pm$	0.36	0.95	—	—	—	—	—	—	—	1.28	—	—	11.6	—	—	$\sigma_a\pm$
$\sigma_g{}^{\times}$	—	—	2.35	2.12	2.95	2.38	1.07	1.02	1.22	—	1.06	1.10	—	2.98	2.25	$\sigma_g{}^{\times}$
M	7.37	8.26	163	182	165	35.0	67.0	94.6	38.3	10.6	66.2	4.83	25.1	99.2	36.8	M

[1] Identification of Symbols:
Σ—Summation.
N—Total No. of observations.
Max—Maximum observed value.
Min—Minimum observed value.
M_o—Crude mode obtained by observation of the frequency distribution or most probable number on the frequency distribution curve. A plus or minus sign following the recorded number indicates the relative position of the true modal value
M_d—Median value of the frequency distribution.
C_{fd}—Characteristic of the frequency distribution curve whether arithmetically normal or geometrically normal.
M_a—Adjusted arithmetic mean obtained from an arithmetic-probability plot.
M_g—Adjusted geometric mean obtained from a logarithmic-probability plot.
$\sigma_a\pm$—Arithmetic standard deviation.
$\sigma_g{}^{\times}$—Geometric standard deviation.
M—Crude arithmetic mean.

[2] Except for unincorporated places wherein unofficial estimates are used.

[3] From nearest major weather station. Averages for 30 years to 1955.

[4] From nearest major weather station.

[5] Evaporation data from Bureau of Plant Industry pans and adjusted by coefficient to pond or reservoir values; years of record ranged from 3 to 39. Precipitation data for 30 years preceding 1955.

TABLE II.—Type of Waste Received at Treatment Facility

Type	Number Reported	Per Cent of Total Reported
Domestic sewage	24	50
Domestic sewage plus industrial waste	24	50
Total	48	100

represent composite hourly samples in proportion to rate of flow.

It should be noticed that on the average there was a 24 per cent reduction in the total alkalinity of the effluent water relative to the influent to the pond. This indicates that there was considerable utilization of carbon dioxide from carbonates and bicarbonates and since the pH value also showed a definite increase, the carbon dioxide thus obtained apparently was photosynthesized into organic material in the form of algal cells or lost to the atmosphere.

TABLE III.—Frequency Tabulation of Pretreatment Devices

Type of Device*	Number Reported	Per Cent of Total Reported
C_i	123	67.5
C_i F_{tn}	12	6.5
C_i F_{th}	12	6.5
None	8	4.4
C_m	6	3.3
C_s	4	2.2
C_m F_{th}	4	2.2
C_m F_{th} C_m	4	2.2
C_i F_{th} C_p	2	1.0
C_i F_{th} F_{tn}	1	0.6
C_m C_i	1	0.6
C_i F_d	1	0.6
Hays	1	0.6
C_i Hays	1	0.6
C_m F_{th} C_m F_{th} C_m	1	0.6
C_m A_a	1	0.6
Total	182	100.0

* Identification of symbols:

C_i—Imhoff tank.
F_{tn}—Standard rate filter.
F_{th}—High rate filter.
C_m—Sedimentation with mechanical equipment.
C_s—Septic tank.
C_p—Plain sedimentation.
F_d—Dunbar filter.
A_a—Activation.

TABLE IV.—Arrangement of Ponds Having More Than One Cell

Arrangement	Number Reported	Per Cent of Total Reported
Series only	30	81.1
Series and/or parallel	4	10.8
Series and parallel	1	2.7
Series or parallel	1	2.7
Parallel only	1	2.7
Total	37	100.0

The geometric mean values for chloride concentrations in the waste water entering and leaving the ponds show the effect of concentration due to evaporation losses. BOD measurements of raw or primary settled waste waters flowing into waste stabilization ponds may be accepted as falling within the limits of accuracy of the BOD test. Influent waste water from secondary treatment devices, however, may or may not be highly nitrified; statistical results including these values could introduce considerable error. Of more serious consequence, is the likelihood of error arising from the application of the conventional BOD technique to effluent pond sam-

TABLE V.—Frequency Tabulation of Recirculation Provisions

Recirculation	Number Reported	Per Cent of Total Reported
None	17	68.0
Pond effluent to Imhoff tank	4	16.0
Pond effluent to sedimentation tank	2	8.0
From any pond to any other pond	1	4.0
Pond effluent to plant[1]	1	4.0
Total	25	100.0

[1] No designation of treatment plant element was given.

TABLE VI.—Disposal of Final Effluent

Effluent Discharged to	Number Reported	Per Cent of Total Reported
Stream or stream bed	80	45.7
Land for irrigation	74	42.3
Air and ground via evaporation and seepage (no effluent)	21	12.0
Total	175	100.0

TABLE VII.—Miscellaneous Conditions Related to Waste Stabilization Ponds

Questions	Number of Answers Obtained			Per Cent of Total Answers	
	Yes	No	Total	Yes	No
Mosquito problem exists	6	20	26	23	77
Odor complaints arise	9	60	69	13	87
Effluent appears clear	38	6	44	86	14
Fish present in pond	31	36	67	46	54
Ducks use pond	54	13	67	81	19
Process recommended	69	1	70	99	1

ples which undoubtedly had extremely variable concentrations of algae present. These algae may have generated oxygen during the incubation period if light was not carefully excluded, or they may have been antagonistic to the sewage seed employed, resulting in two possibilities: if the algae died the dead cells would exert additional BOD; if the algae lived and killed off the bacteria there would be little or no BOD exerted. In short, the BOD results involving effluent measurements and BOD efficiency of the system should be interpreted with caution. The numerical values presented for the remaining physical and chemical parameters require no comment for interpretation.

Climatology, Land Irrigation, and Detention

The average figures given for temperatures, wind speed, possible sunshine, sky cover evaporation minus precipitation, area of land irrigated, and detention period are all considered representative with no serious limiting factors. With the exception of land area under irrigation these parameters are all interrelated. The practice of operating dead-end ponds (no outlet) should be discouraged since most of this water is lost to the atmosphere. On the other hand it should be pointed out that the shorter the detention period the smaller the pond; the cheaper the initial cost, the lower the evaporative losses, and the less the likelihood of excessive algal buildup.

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TOTAL OXIDATION TREATMENT OF ORGANIC WASTES *

By

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The treatment process providing total oxidation of organic wastes has developed in the last few years into an important method of waste treatment. The fact that total oxidation of organic wastes is feasible is not a new concept; however, the method of applying it to the treatment of domestic and industrial wastes is recent. Many years ago field sanitary engineers, in the course of operating sewage treatment plants, recognized that, in some instances, it was possible to build up and maintain mixed liquor solids in an aeration tank at relatively fixed levels without wasting any activated sludge in order to control the concentration of solids. This phenomenon usually occurred in plants where the actual flow was considerably less than design and where consequently the aeration period was considerably longer than design. While this phenomenon was recognized, it was considered to be an operating problem which existed when a plant was underloaded rather than a potentially important tool. It was not until many years later that aeration was applied in a manner so as to take advantage of these observations.

Initially the process † was applied to the treatment of dairy wastes. It was first applied to this type of waste, since the solids present are primarily organic and for the most part soluble, so that there is no need for primary settling to remove easily settled solids.

The success of the dairy waste treatment plants led to the application of the same process to the treatment of domestic sewage. The use of the process for the treatment of domestic and industrial wastes has since developed to the point where there are approximately 175 plants installed or in the process of construction.

Process Application

This total oxidation process consists primarily of comminution of the sewage, long-period aeration, final settling of the sludge, and return of the settled sludge to the aeration tank. Figure 1 shows flow diagrams for an activated sludge plant and a plant adapted to use the Ratedaeration design. This shows the simplified layout of the complete oxidation type of plant. Primary settling and sludge digestion are eliminated, while the aeration system in the total oxidation unit is enlarged to provide the required aeration period.

Application of the process has been primarily for schools, small subdivisions, factories, shopping centers, clubs, and trailer parks. The installations are relatively small, ranging from a minimum of 2,000 gpd to approximately 200,000 gpd. The lower flows are handled by fabricated steel units, shipped completely assembled to the job site. A single unit of this design has a maximum capacity of 7,500 gpd

* Presented at the 1957 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; University Park, Pa.; Aug. 28–30, 1957.

† Now known as Ratedaeration. This is a trademark of the Chicago Pump Company for the design, supervision and installation of equipment in accordance with its developed process.

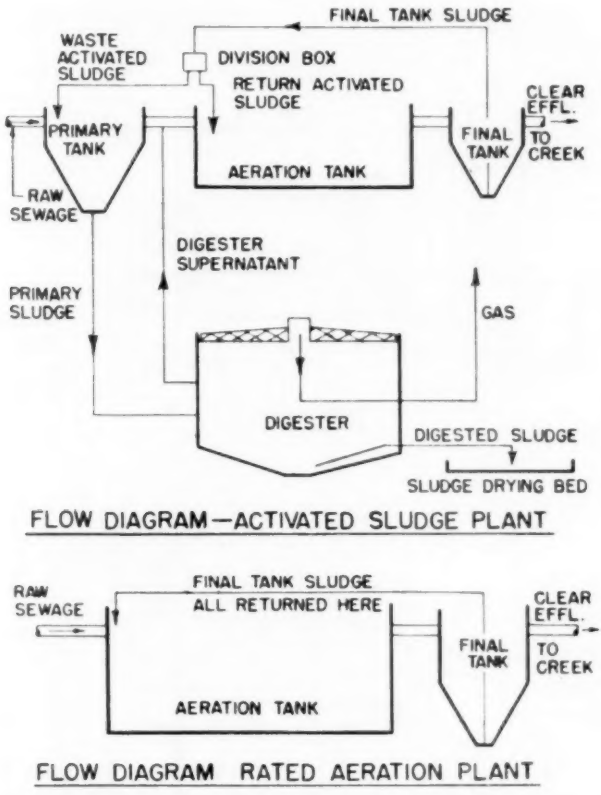

FIGURE 1.—Flow diagrams of activated sludge process and Ratedaeration process design.

and, under some conditions, duplicate units are used, bringing the maximum capacity in this type of unit up to 15,000 gpd.

Figure 2 shows the type of unit used for low flows. In this package unit flow enters through a comminutor and drops directly into the aeration tank. Air is provided by the blower mounted on the top of the tank and is diffused though disc diffusion units * mounted on a swing diffuser. The mixed liquor passes through a perforated baffle into the final settling compartment. Sludge is returned from the settling compartment by gravity.

The fabricated unit is mounted on a concrete pad after which the influent and effluent lines are hooked up and power connected. After backfilling, the plant is ready to be put in service.

For flows above 7,500 gpd the plants are usually built of concrete. Figure 3 shows a plan view of a typical layout for these flows. In these larger plants, the final settling tank can be constructed with a hopper bottom or can be equipped with a sludge collector, depending upon the size. Return of the sludge from the final tank is made by means of air lift and is discharged ahead of the comminutor. Duplicate blowers are normally provided, and a water spray system is included to control froth on the aeration tank.

* Discfuser is a trademark of the Chicago Pump Company for its disc diffusion units.

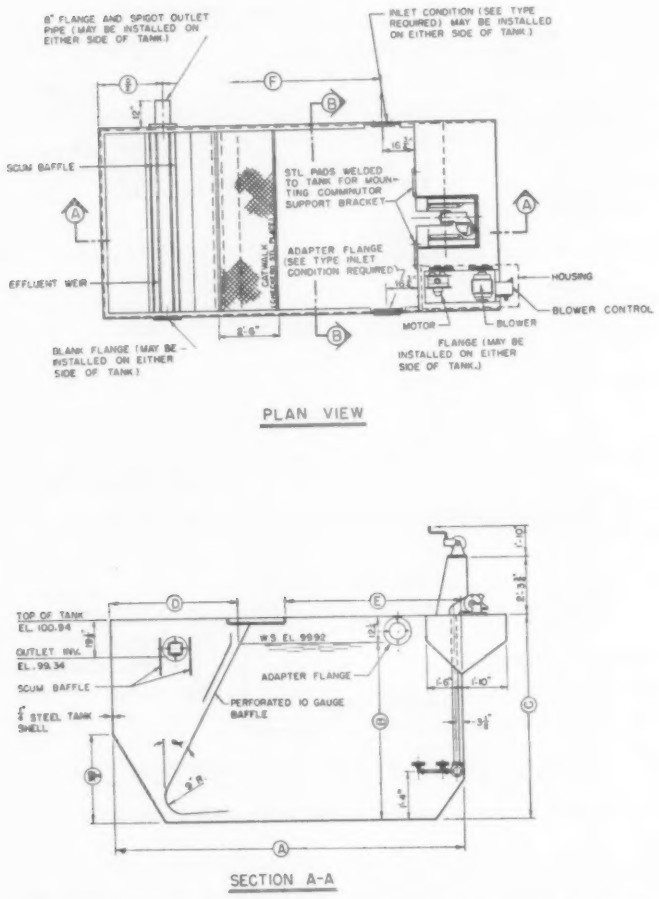
8" FLANGE AND SPIGOT OUTLET PIPE (MAY BE INSTALLED ON EITHER SIDE OF TANK)
INLET CONDITION (SEE TYPE REQUIRED) MAY BE INSTALLED ON EITHER SIDE OF TANK)
SCUM BAFFLE
STL PADS WELDED TO TANK FOR MOUNTING COMMINUTOR SUPPORT BRACKET
ADAPTER FLANGE (SEE TYPE INLET CONDITION REQUIRED)
EFFLUENT WEIR
CAT WALK
HOUSING
BLOWER CONTROL
MOTOR
BLOWER
BLANK FLANGE (MAY BE INSTALLED ON EITHER SIDE OF TANK)
FLANGE (MAY BE INSTALLED ON EITHER SIDE OF TANK)
PLAN VIEW
TOP OF TANK EL. 100.94
OUTLET INV. EL. 99.34
SCUM BAFFLE
STEEL TANK SHELL
W.S. EL. 99.92
ADAPTER FLANGE
PERFORATED 10 GAUGE BAFFLE
SECTION A-A

FIGURE 2.—Package unit to handle total oxidation of low flows.

In Figure 4 is shown a small plant of this type treating dairy wastes. Figure 5 shows a large plant which is designed for 175,000 gpd and treats the wastes from a subdivision of 600 homes.

Design Factors

Since these plants are being used primarily in small installations where there is a minimum amount of operation supervision available, the design of the plants has been conservative so that accurate control of operational variables is not needed.

Aeration Period

For the normal domestic type of installation, the aeration period provided is 24 hr, with a BOD load not to exceed 30 lb/1,000 cu ft of aeration capacity. This BOD loading, expressed in terms of pounds of BOD per 100 pounds of mixed liquor solids, will range between 12 and 16 lb for mixed liquor solids of 4,000 and 3,000 ppm, respectively. Actually, since the volatile content of the mixed liquor solids is very low, loadings should more correctly be expressed in terms of volatile solids con-

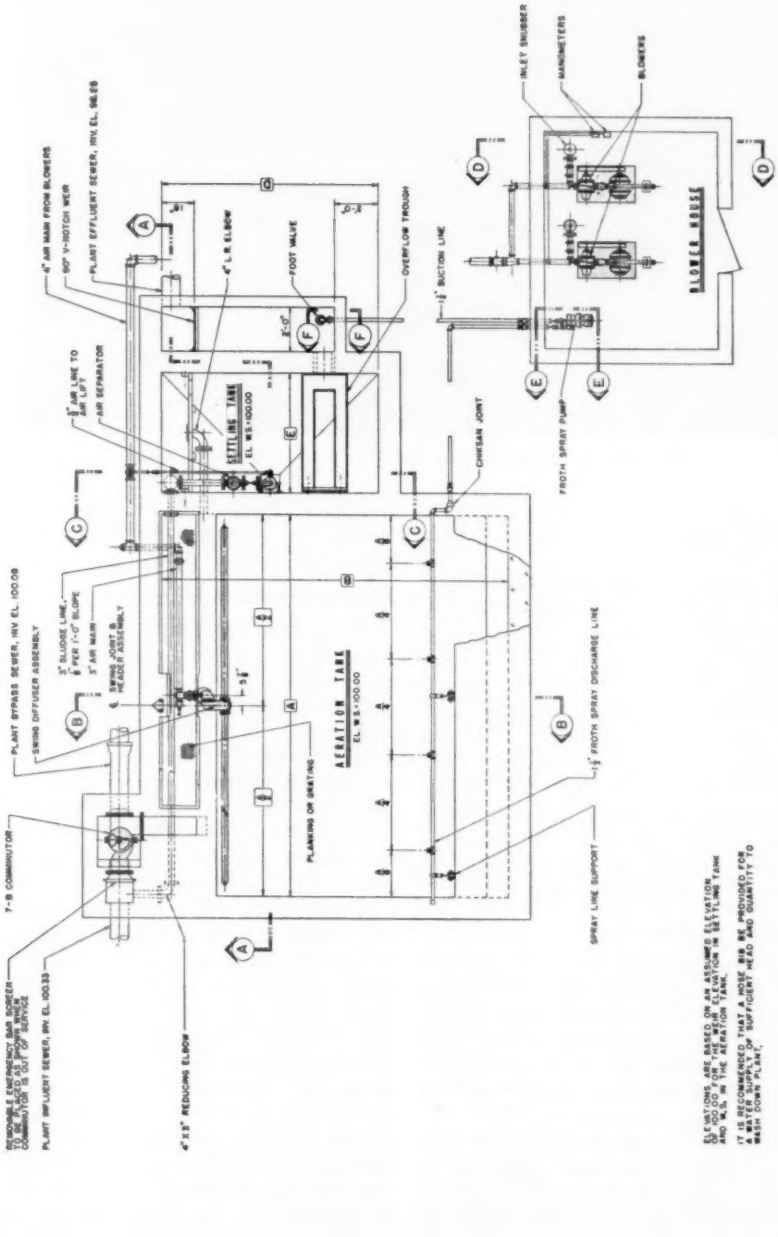
4" AIR MAIN FROM BLOWERS
90° V-NOTCH WEIR
PLANT EFFLUENT SEWER, INV. EL. 96.68
1" AIR LINE TO AIR LIFT
AIR SEPARATOR
4" L.R. ELBOW
FOOT VALVE
OVERFLOW TROUGH
SETTLING TANK
EL. WS-100.00
INLET SNUBBER
MANOMETERS
BLOWERS
BLOWER HOUSE
4" SUCTION LINE
CONVEAN JOINT
FROTH SPRAY PUMP
PLANT BYPASS SEWER, INV. EL. 100.09
SWING DIFFUSER ASSEMBLY
3" SLUDGE LINE, 1/4" PER 1'-0" SLOPE
3" AIR MAIN
CONVEAN JOINT & HOSE ASSEMBLY
AERATION TANK
EL. WS-100.00
PLANKING OR GRATING
1/2" FROTH SPRAY DISCHARGE LINE
SPRAY LINE SUPPORT
REMOVABLE EMERGENCY BAR SCREEN TO BE PLACED IN POSITION WHEN COMMINUTOR IS OUT OF SERVICE
7-B COMMINUTOR
PLANT INFLUENT SEWER, INV. EL. 100.33
4"x3" REDUCING ELBOW
ELEVATIONS ARE BASED ON AN ASSUMED ELEVATION OF 100.00 FOR WATER LEVEL IN SETTLING TANK AND 100.00 FOR WATER LEVEL IN AERATION TANK.
IT IS RECOMMENDED THAT A HOSE BIB BE PROVIDED FOR A WATER SUPPLY OF SUFFICIENT HEAD AND QUANTITY TO WASH DOWN PLANT.

FIGURE 3.—Plan view of treatment plant to handle daily flows above 7,500 gal.

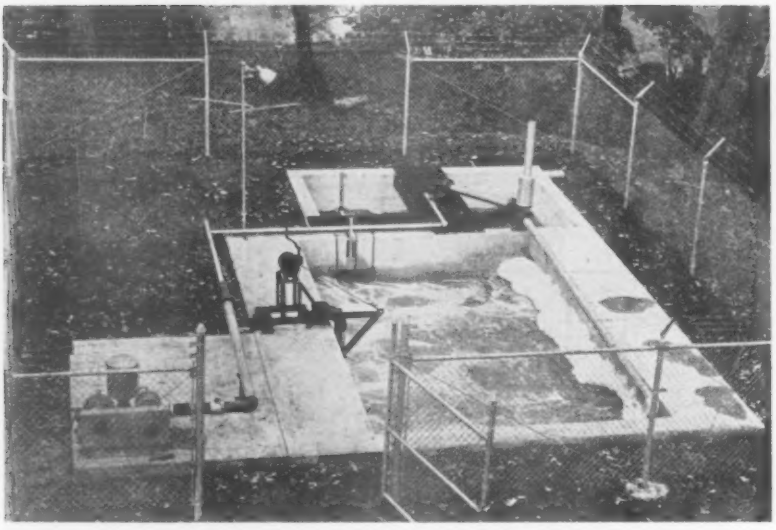

FIGURE 4.—Ratedaeration installation treating dairy wastes.

tent of mixed liquor, in which case the loadings may be as much as double those stated above.

In practice it has been found that even though there are rather extreme fluctuations in flow, the provision of aeration capacity equal to the total 24-hr flow is ample. Even though all of the flow is introduced to the plant in a matter of 8 to 10 hr, it is not necessary to design the aeration tank upon the rate of flow, but rather it can be designed upon providing a capacity equal to the total flow. This is due primarily to the equalizing factor of the high return sludge rate.

Settling Tank

For the settling tank, design has been based normally upon providing 4 hr detention time based upon the 24-hr flow. If, then, the rate of flow is as much as double the 24-hr average, a final settling detention time of half the design is still obtained, or 2 hr.

Since the solids developed in this process are for the most part low in volatile content and, therefore, high in ash, the settling rate of the sludge is very good and little difficulty is ever had with bulking of the sludge even though the settling period may become relatively short at times.

Return Sludge System

The return of sludge from the settling tank has been made as simple as possible by use of an air lift in practically all applications except the small steel tank units where gravity return is usually employed. Control of the discharge is made simply by control of the air volume applied to the unit. Return of the sludge is continuous and at an extremely high rate as compared to normal activated sludge practice. In the Ratedaeration method the return rate is usually a minimum of 100 per cent and is frequently as much as 300 per cent of the design flow. This high return sludge rate is an extremely important part of the process and contributes a great deal to successful operation. By returning the sludge at a high rate, the entire system is kept completely aerobic at all times. This condition is responsible for optimum oxidation rates and tends to smooth out any peaks in influent loadings. Thus, the oxygen demand of

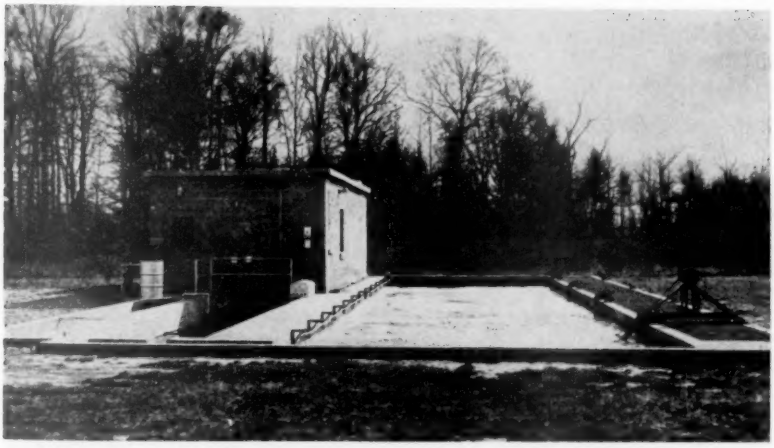

FIGURE 5.—Treatment plant accommodating a subdivision of 600 homes.

the mixed liquor is maintained at a relatively constant level, even though the flow and/or BOD load fluctuates materially. Since the oxygen demand level does remain relatively constant, the air applied to the system can be constant and, therefore, it is not necessary to exercise any appreciable control over the quantity of air applied.

Air Requirements

Air requirements are based upon the maximum BOD load or on the necessary circulation velocity, whichever is the higher, plus the amount needed for operation of the return sludge air lift. The volume of air required to treat any waste depends upon the organic load applied and the rate of oxygen transfer. Various types of air diffusion units are used to make the oxygen available to the system. One diffuser used is the previously mentioned disc-type, which is non-clogging and contains an automatic shutoff feature so that intermittent air discharge can be employed. Another type used is a diffuser tube in which air application is approximately 1,000 cu ft per day per pound of BOD. With disc diffusers the air supply is approximately 1,500 cu ft per day per pound of BOD. Air requirements for circulating velocities are a minimum of 3 cfm per lineal foot of aeration tank.

Operation

In operation, the plants employing Ratedaeration design developed a mixed liquor solids concentration which is dependent upon the BOD load introduced to the plant. It seems to make relatively little difference as to the type of sewage treated since data from numerous dissimilar types of facilities have indicated a similar range in concentration of mixed liquor solids. In most cases, this concentration is between 3,000 and 5,000 ppm and has ranged as high as 12,000 ppm. The actual concentration of mixed liquor solids, of course, is not indicative of the type of treatment being obtained at different installations, since the volatile content of the sludge is the most important factor. In most plants employing the process, however, the volatile content of the sludge is relatively low, particularly after the plants have been in operation for a few months.

In a standard activated sludge treatment plant, the volatile solids of the mixed liquor can be as high as 85 per cent and seldom are below 65 per cent. The volatile solids in this new aeration

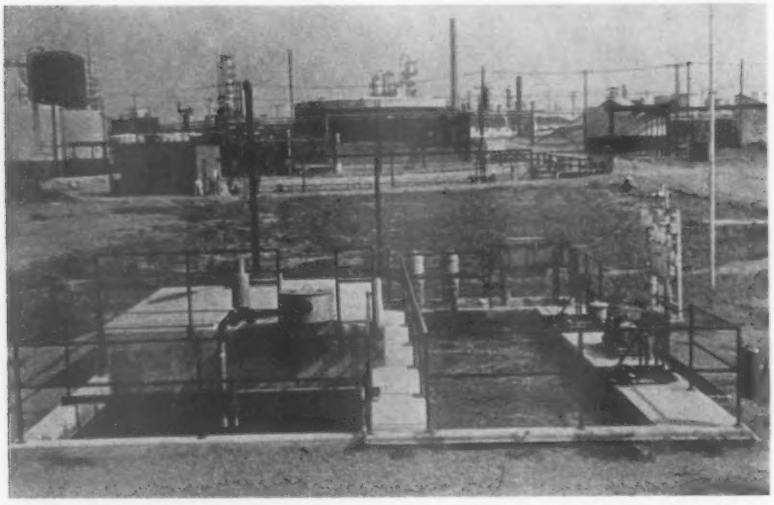

FIGURE 6.—Treatment unit handling sanitary wastes of a refinery. Unit includes a sludge-holding tank.

process are frequently as low as 50 per cent and sometimes even lower. This is due to the fact that the oxidized material in the sludge is of much greater concentration than in the standard activated sludge plant and, therefore, results in a heavier sludge.

The concentration of solids in the mixed liquor may, after a long period of time, reach a high level and, in that case, a portion of the sludge can be wasted to reduce the concentration to more normal conditions. This wasting of sludge can be taken care of by the addition of a sludge-holding tank to the system, and periodically a portion of the return sludge is wasted to this holding tank. Figure 6 shows an installation utilizing this design. This treatment plant serves a refinery.

When sludge is wasted to the holding tank, it is done on an intermittent basis, simply to reduce the solids concentration in the aeration tank. Ultimately, the wasted sludge must be drawn from the sludge-holding tank when the tank becomes full. When sludge is wasted, it must first be concentrated in the settling tank by reducing the rate of return sludge, and then the concentrated sludge is wasted to the holding tank. Wasting sludge for a short period weekly is usually all that is required to maintain the solids concentration at a normal level. In general practice, however, it has been found that the solids concentration in the aeration tank is maintained at relatively fixed levels over extended periods of time without the necessity of wasting any sludge.

Another method which can be used to control the sludge concentration is to waste a portion of the mixed liquor solids to an auxiliary aeration unit in which the volume wasted is aerated for periods up to 48 hr, with ultimate removal of the concentrated solids being made to a small sludge bed or being pumped into a tank truck and disposed of by trucking away.

Results

Originally, these plants were expected to produce an intermediate degree of treatment similar to that produced by a trickling filter plant. However, in general, the results have proved to be considerably better and, in most cases, the BOD reduction ranges be-

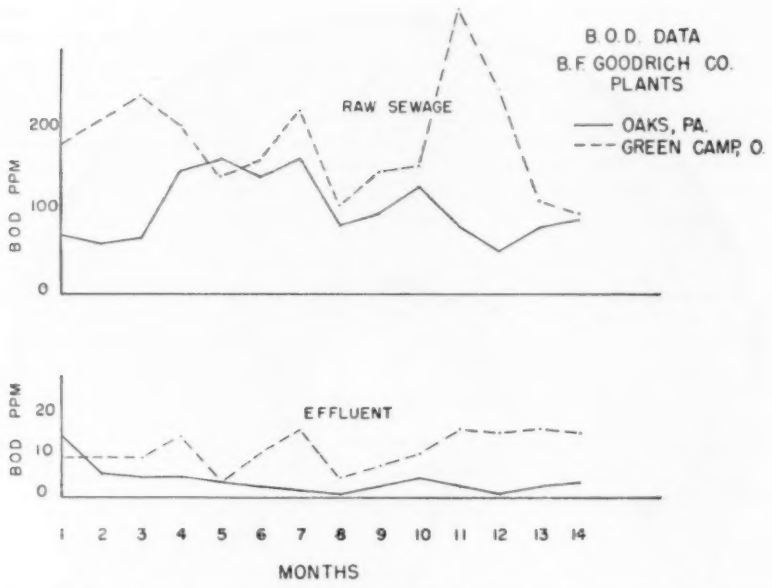

FIGURE 7.—BOD performance data from total oxidation treatment units at two B. F. Goodrich Company plants.

tween 80 and 90 per cent. While the degree of control which can be maintained at a plant of this type is minimum, it is true that those plants which are given the most care will produce the best results. In actual practice, the degree of operation control is almost negligible and maintenance of equipment is primarily the only factor involved. With plants of this capacity, it is obviously less expensive to provide a little more horsepower on the blower than it is to have an operator run control tests on dissolved oxygen and mixed liquor suspended solids.

BOD data for two of B. F. Goodrich Company's plants are shown in Figure 7. These data are averages of BOD tests taken normally six to seven times a month. The curves show the variation in the inlet and effluent BOD. It can be seen that the strength of the sewage at one plant is somewhat lower than that at the other plant; however, the effluent BOD is low in both cases. The smaller plant was designed for approximately 5,000 gpd, whereas the larger plant was designed for 54,000 gpd. The smaller plant is operating under full load at the present time, whereas the larger plant is operating over design loading. These data are typical of the results obtained at many other similar type plants.

Figure 8 shows one of the daily flow charts for the larger plant. The chart shows very graphically the peak flows encountered at changes of shift when men are cleaning up. The flow indicated for that day was 72,500 gal and the peak rates range up to 300,000 gpd.

This process is, of course, subject to some difficulties and these have been primarily in connection with the application of too much air and excessive length aeration period. In some cases, particularly in schools, where the flow has been below design and the aeration period as long as 48 hr, nitrification has developed with the result that the sludge in the final settling

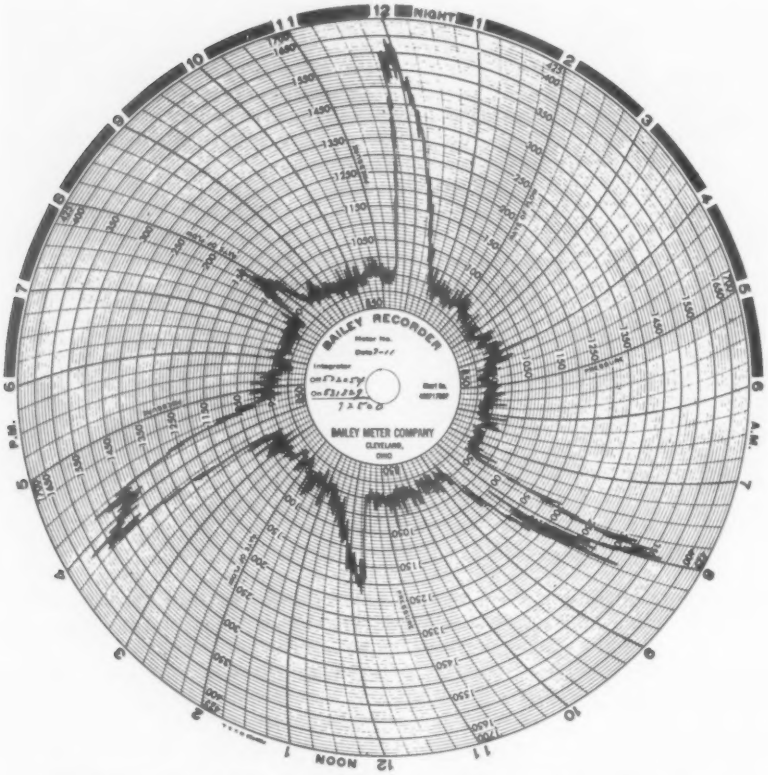

FIGURE 8.—Daily flow record from the larger of two treatment units at B. F. Goodrich Company.

tank has floated to the surface. This problem has been controlled by reducing the volume of air applied to the system. In a number of cases where these plants are utilized in schools, the aeration is completely shut down over the weekend. This procedure is exactly opposite to activated sludge operational practice where power failure would be the only cause of air supply interruption. However, these facts point up the differences in operating requirements between the two processes. It is shown that under certain conditions this process exhibits considerable flexibility.

In other applications, the air volume is adjusted to the load by means of variable sheaves on the belt-driven blowers or by the utilization of time clock control on the blowers. If this latter method is used, the air diffusion media must be of a non-clogging type with a shutoff feature so that the sludge will not re-enter the diffusion media. Either this type of unit must be used or the diffusion units can be swung out of the tank when the blower is shut off. In most of these total oxidation plants the non-clogging disc-type of aeration unit, with a built-in valve action to prevent backflow, has been used.

Cost

The development of these plants was based primarily upon the fact that a low cost type of treatment system was

desired which would have the advantages of giving complete treatment and yet require a minimum of maintenance. With the use of this type of aeration plant, savings in construction are realized due to the lack of need for a primary tank, a sludge digester, and sludge drying beds. In general, a plant of this type can be built for between one-half and two-thirds of the cost of a conventional treatment plant of the same capacity and providing the same degree of treatment. This allows construction of plants giving adequate treatment for small installations which otherwise would find conventional treatment costs to be an excessive burden.

Summary

Total oxidation of organic wastes can be accomplished in simply designed waste treatment plants requiring a minimum of maintenance and control. Design of the plants determines the degree of treatment obtained or the "rating" of the system; therefore, the equipment manufactured and used for treatment has been called the Rated-aeration process.

This process is particularly suited to treat the wastes from schools, motels, factories, dairies, small subdivisions, and a variety of industries. Flows up to 7,500 gpd can be treated in single steel-fabricated units completely equipped when received at the job site. Larger flows are treated in concrete tanks.

The long period of aeration provided results in a stable sludge with a low oxygen demand and excellent settling characteristics. Due to the stability of the system, wide variations in influent load can be handled with little effect on treatment.

The process accomplishes BOD reductions of 75 to 90 per cent. An effluent BOD of less than 20 ppm is consistently obtained when treating normal domestic sewage.

This system is inexpensive to build due to the elimination of costly substructure and extensive piping. Mechanical equipment requiring maintenance is confined to blowers and in some instances pumps, where there is a lift station. Operational control is primarily mechanical maintenance and housekeeping so that such costs are low.

TEN-YEAR INDEX UNDERWAY

The Federation Board of Control at the annual meeting in Boston in October 1957 authorized the preparation and publication of a 10-yr index for SEWAGE AND INDUSTRIAL WASTES for the period 1949 through 1958. This index is now being compiled and will be offered early in 1959. The last comprehensive index was for the period of 1928–1948.

Soon after the last issue of 1958 the Journal will carry an advance announcement of availability and price of the Index.

Industrial Wastes

OBSERVATION AND MEASUREMENT ON REFINERY WASTES *

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The petroleum industry is among the foremost with respect to economic value and tonnage of finished products. It is also near the top of the list in water use (1). Heat transfer and power production require most of this water; a smaller amount, used as a solvent in direct contact operations or for seals in barometric condensers, may be highly contaminated. Contaminants of waste water include hydrocarbons, their oxygen, nitrogen, or sulfur derivatives, and inorganic materials found with the crude oil or added in process.

Waste materials may appear in surface water as an oily emulsion, a surface film, a shoreline deposit, or sludge. Toxic constituents may eliminate desirable forms of aquatic organisms and interfere with natural self-purification. Recreational use suffers concurrently The receiving water may be made unsuitable for municipal use or it may require expensive and elaborate treatment to make it acceptable. Tastes and odors associated with oil pollution are likely to persist longer than other pollutional effects.

Analysis to measure the pollutional load presented by oily wastes is difficult because of the nature and variety of the waste products. There is no simple analytical definition of oil pollution. Generally, oily wastes are characterized by their source, specific effects, or by a particular analytical method. Confusion arises when different individuals approach the problem from dissimilar viewpoints.

The lack of precise measures for waste composition and quality has been and still is the greatest barrier to comprehensive data on oily wastes. As a consequence, relatively little definitive information is available on the behavior of oily waste constituents in water in spite of a long history and common occurrence.

The following discussion seeks primarily to outline work done on oily wastes and related problems at the Robert A. Taft Sanitary Engineering Center, with other material presented as required to place the work in perspective. Methods of analysis are discussed along with the results of application of these methods to promote the understanding of refinery waste behavior in water.

Sampling and Analytical Precautions

Oily waste sampling deserves special consideration because of the variety of biological, chemical, and physical changes and their effects on analysis. A particular determination may require a special sample so that the entire contents of the bottle can be processed in analysis. No satisfactory method has been devised to obtain a

* Presented at the 8th Oklahoma Industrial Wastes Conf.; Oklahoma State Univ., Stillwater, Okla.; Sept. 25–26, 1957.

representative sample of a surface film. Suspended and settleable materials in a waste stream are difficult to sample, but with suitable technique reasonably good results are possible.

Prompt analysis may be required to limit the changes which occur on standing. Highly volatile fractions require one technique; biological, chemical, or other physical changes necessitate other procedures. A.P.I. Method 701–53 (2) discusses the accepted methods for sampling and preservation of oily wastes for a variety of determinations; it may be necessary for the analyst to adopt different techniques to get reliable results for special determinations.

Routine analytical methods normally provide information suitable for many purposes, but sometimes sacrifice specificity to save time and manipulation. Research methods may be necessary to supplement the usual data to resolve anomalous results or to follow a specific waste component in a stream containing numerous interferences.

Oxygen Demand Considerations

It is difficult to present a consideration of waste analysis without discussing factors involved in the use and interpretation of the BOD and COD tests. However, this question has been treated several times previously (3) (4) (5), so that further extended presentation is not warranted. It is perhaps pertinent to recommend use of storage-stabilized receiving water as a substrate in BOD tests, as provided in "Standard Methods" (6).

Oil Analysis

Most analytical methods for oil collectively estimate animal, vegetable, and mineral oil or grease. Coloring material, other nonoily extractables, and colloidal solids may be included. McKee (1) discusses many of the methods and constituents measured by them. Different methods may give significantly different results on the same sample.

Simplified analytical methods may serve to estimate the oil content of a plant effluent, but become inadequate on dilution of the effluent in receiving water. The plant effluent usually includes a definite group of materials derived from contributing processes. The same constituents appear in the receiving water in lower concentrations mixed with an ill-defined collection of extractables from industrial or domestic wastes discharged at upstream locations. Biochemical degradation of various substances produces both soluble and suspended products that may interfere in manipulation or interpretation.

In this laboratory more specific oil determinations were required for investigating the persistence of mineral oil in polluted water. It was found that a combination of soaps, mineral oil, and degradation products in the partially oxidized substrates studied sometimes exceeded the original concentration of added oil. The problem was resolved by use of liquid-liquid extraction, infrared determination, and chromatographic separation of oils and oxy materials (7). Mineral oils from the mixed extract were not retained on an alumina column. Oxy materials were retained to a degree depending on their polarity. Infrared determination before and after chromatographing the extract classified the sample by functional groups, verified chromatographic separation, and provided an estimate of the percentage of hydrocarbons in the original extract.

Phenol Analysis in Refinery Streams

Phenols occur in refinery streams and are of interest principally because of their relation to taste and odor problems, which are discussed later. Analytical methods for phenol are highly sensitive. Specificity leaves something to be desired, but the available methods have been adequate to provide more information on stream behavior of phenols than for most other

organic materials. It has been shown by Elkin and others that phenols in refinery wastes can be destroyed biologically by activated sludge (8) and cooling tower (9) operation.

Methods recommended for the phenol determination by "Standard Methods" (6) include the Gibbs and 4–aminoantipyrine (4–A.A.P.) procedures; the A.P.I. (2) recommends the 4–A.A.P. and nitrosophenol methods. Mohler and Jacobs (10) report comparative data on refinery waste samples with five different phenol procedures, including those listed. They favor the 4–A.A.P. method as the most practical available phenol determination, on the basis of precision, sensitivity, time requirements, applicability, and reagent stability. Its most obvious disadvantage is the inability to measure para-substituted phenols.

Comparative results showed appreciable variation in the data when different methods were applied to the same sample; a consistent ratio between methods on various samples was not shown. In general, the nitrosophenol results were slightly lower than those of the Gibbs procedure; the 4–A.A.P. results were higher. Ratios between phenol concentrations with different methods appeared to be associated with individual sample composition and the effective reactivity of the particular phenols with the color-producing reagents (10).

Suitable isolation of phenolic materials from interference frequently represents the difference between good and indifferent results. Sample characteristics and behavior during analysis represents the only available guide on this question. Several procedures for phenol purification, including distillation and extraction, are described in "Standard Methods" (6).

Carbon Filter Technique

The possible relationship of refinery wastes to impaired taste and odor qualities of raw water has been a recurrent problem that is not subject to resolution by consideration of phenols alone. It is desirable to isolate, identify, and measure waste components that may cause the undesirable taste and odor. It is usually necessary to concentrate the organic materials in a waste prior to classification and analysis. One method for concentration is to pass a suitable quantity of sample through an activated carbon filter. The adsorbed organics are then eluted from the carbon with chloroform or other organic solvent. The residue after distillation of the solvent can then be examined in a variety of ways.

A useful separation of the mixed residue can be made by taking advantage of solubility differences. Principal groups separated include ether insolubles, water solubles, weak acids, strong acids, neutrals, and basic materials. Taste and odor tests on these groups will indicate which of the materials have the most intense malodors or tastes. The neutral components, usually the largest of the groups, lend themselves to further separation into aliphatic, aromatic, and oxygenated materials by chromatographic means. The chromatographic step is critical in achieving separations suitable for evaluation. Infrared tests on the separated and purified fractions may be revealing. Comparison of the infrared spectra of waste components recovered from refinery waste and of organics recovered from drinking water suspected of containing the contaminants may offer reliable evidence of the presence of oil pollutants. Thorough knowledge of other types of pollutants in the area is necessary before interpretations are made. A study using such procedures has been described in detail (11).

Concentration of organic components can also be accomplished by the use of liquid extraction methods. In general, the extraction methods would be preferred if the concentrations would permit sufficient recovery of organic

material from a sample of reasonable volume (20 to 50 l). The carbon adsorption procedure is usually required on tap waters and most surface waters.

Carbon adsorption and elution techniques are not quantitative. However, controlled conditions of sampling and analysis permit comparisons of different samples. There is sound evidence that the major portion of contaminants is recovered from samples containing oily wastes. Components with equal or greater volatility than gasoline may be lost during manipulation. A sensitive procedure for identification and determination of volatile hydrocarbons in water has been published (12). The method is limited to hydrocarbons boiling up to 400°F and requires the use of a mass spectrometer.

Pollutional Characteristics and Behavior

Studies of refinery wastes as possible factors in taste and odor problems with municipal water supplies has led to a series of investigations in the recent past and is a recurrent problem presented to the Sanitary Engineering Center. Background studies based on carbon filter sampling or liquid-liquid extraction of effluents from a number of refineries have developed information on the quantity, chemical, and organoleptic characteristics of organic materials in a group of refinery effluents (13).

The neutral components from five different refineries constituted 65 to 87 per cent of the total chloroform-extractable materials. This group could be detected by odor tests in the range of 19 to 64 ppb concentration. The other groups also had thresholds in a similar range, but their relative quantities made them less significant as potential trouble makers. Phenolics must also be considered in the light of their potential increase in taste intensity by chlorination. Because the neutral materials, which include highly odorous sulfur compounds, are in general more resistant to biological purification than are the other groups, they would be expected to travel farther and persist to reach water supply sources.

Based on an average recovery of 50 ppm of oily materials from effluents and on a reasonable average threshold odor of the total extract of 50 ppb, it is indicated that a factor of 1,000 is required for dilution in order to bring these materials to threshold levels. These results reflect only relatively nonvolatile components. In practice the volatiles may contribute to contamination of nearby water sources and the dilution required to reach threshold levels may be several times the 1,000 factor found in these tests. When it is considered that a large refinery may discharge 100 mgd of water, the magnitude of the potential taste and odor contributions of these wastes is obvious.

Rosen and Middleton (13) attempted to follow the travel of refinery waste in water in the presence of many other industrial wastes from a large metropolitan district. The neutral fraction of carbon filter adsorbates was separated chromatographically into aliphatic, aromatic, and oxy fractions. Infrared curves of the aromatic and aliphatic fractions of the neutrals showed striking similarities in the effluents of five different refineries. The carbon filter technique was applied to receiving waters at varying distances from refinery discharges and provided an indication of the waste travel. Water samples obtained near refinery discharges gave clear analytical evidence of the presence of refinery waste. As distance increased, oxy products were more evident and the infrared curves obtained on various fractions were modified by disappearance of some bands and addition of others. Although comparisons were more difficult for the distant stations, recorded data suggested the likely origin of the waste and the modifications since discharge. Data such as these have infinitely

greater possibilities than those from subjective tests, such as taste or odor.

Phenolic Fractions

In giving consideration to the phenolic materials it should be remembered that their taste intensity may be increased as much as 500- to 1,000-fold when chlorinated at the water plant. Even in the presence of substantial quantities of other refinery pollutants, phenols may be the only constituents which cause difficulty. In one instance, when 50 ppb of phenol was demonstrated in the raw water and when other materials of refinery origin were present in amounts of 200 to 300 ppb, the taste in the drinking water was unmistakably associated with the chlorinated products of phenol. This occurrence appeared at a time of cold water conditions and rapid flow from the refinery waste discharge to the water plant intake. Under summer conditions and low water flows similar amounts of phenols were present but the water also contained extraordinarily large blooms of algae and other aquatic organisms. Chloroform-extractable organics totaled approximately 700 ppb. The taste and odor in the drinking water was offensive, but it was not characteristic of the chlorinated phenolics experienced during the winter months. It appears that the mixture of organics contained materials capable of masking the odor of phenolic substances.

Phenols may enter surface waters from many sources. However, high concentrations are generally the result of industrial effluents. Phenols frequently have been noted in association with many undesirable effects not necessarily caused by their presence. Although phenols have earned much of their reputation for water quality degradation, other materials less extensively studied can produce similar effects.

Ettinger and Ruchhoft (14) reported that removal of phenol from aerobic surface water largely was due to biological action. Several surface water sources were tested; all resulted in similar metabolic destruction of phenols, but at significant differences in rate, depending on source, conditions, and type of phenol. The first of several doses exhibited a longer disappearance time than subsequent doses. This indicates a high degree of acclimatization of the biota to phenol degradation. Decomposition appeared to be associated with the variables common to other biological processes, such as initial biota (types and numbers), concentration, nutritional balance, temperature, etc.

Anaerobic persistence of phenols (15) was somewhat greater than for aerobic systems. Destruction was evident in all substrates tested, and indicated similar acclimatization. Flowing water under ice cover offers opportunity for the greatest travel for phenols because of low temperature and oxygen tension.

It is not possible to predict the disappearance time of phenols for a given stream because of the many variables influencing decomposition. The past history of the receiving water and the possibilities for developing and maintaining an acclimated phenol-consuming population are among the more important considerations.

Definitive Studies of Oil Pollution Travel

The studies of the behavior of oil as a pollutant in very complicated situations logically suggested studies of oil in situations where a minimum amount of environmental complications existed. Accordingly, the behavior of oil was studied first in the laboratory (16) and then in a small stream (17) selected because significant oily waste discharge occurred at only one location. The dry weather flow of the stream was composed of a mixture of refinery effluent and municipal activated sludge effluent.

Oily wastes entered the stream primarily as emulsified material. Oil globules were soon trapped in flocculent biological solids, which agglomerated and settled (17). Milky appearance in the water disappeared after this sequence. Silt was trapped along with the oil and appeared to hasten sedimentation by increasing the density of the combined mass. Sediment quickly became anaerobic in warm weather. Gasification of sludge tended to lift oil and sludge solids into the flowing water and to produce a minute oil fleck at the surface when a gas bubble broke through. The lifting action assisted in moving sedimentary deposits downstream during warm weather low flows. A substantial stream rise would flush out the channel deposit.

Low stream water temperatures reduced sedimentation of oil to a marked degree. The emulsified appearance cleared slowly, with little evidence of sludge production. There appeared to be relatively little change in the waste load with downstream distance during cold weather. During the summer gross sludge deposits first occurred after about 4-hr passage time below the discharge (approximately 1 mile). Emulsified oil disappeared and organic loading decreased rapidly during sedimentation. Mineral oil content of the flowing water below the sludge deposits showed a reduction of about 75 per cent as compared with that above the deposition zone.

Biological growth in the deposition zone consisted almost entirely of plankton, fungi, and bacteria. With increasing downstream distance from the sludge deposits, a greater variety of organisms appeared. Clean water organisms were established about 30 miles below the refinery outfall. Marginal deposits of oily clay were evident at this point and had a marked effect on water quality when disturbed.

Samples of oily sludge from the stream were subjected to anaerobic decomposition in the laboratory for a period of 125 days at 5°, 20°, and 35° C. No measurable loss of mineral oil was detected, although other organic materials gradually disappeared.

Laboratory results (16) on aerobic oxidation showed 50 to 80 per cent conversion of suspended mineral oil to carbon dioxide per week at 25° C. Oil metabolism and emulsion break were not detectable in 60 days at 4° C. The behavior of laboratory oxidations was similar to that in the stream except that the emulsion break and sedimentation occurred much more rapidly in the stream. It is possible that oxidation also occurred more rapidly in the stream, but this was not verified. The small percentage of suspended oil during warm weather and the inhibitory effect of low temperatures on oxidation are deemed likely to reduce oil oxidation in the stream to relatively small values except over an extended time.

In the stream studied, oily waste behavior appeared to be primarily a function of sludge action. The sediment formed a reservoir of polluting material that was returned to the flowing water at a rate depending on gasification and flow turbulence. Hydrocarbon decomposition was limited primarily to the attrition of oil available under aerobic conditions. Apparently there is a major accumulation of oil as sludge in the stream bed during low flow periods. This accumulated sludge is flushed out by major stream rises, putting oily deposits above the normal water line in otherwise clean water zones with other possible damage to stream use.

Summary

Some progress has been made in measuring oil refinery pollutants, in studying the fate of the materials in water, and in understanding the role of these wastes as industrial pollutants. Some of the procedures used are tedious and expensive. More specificity is desirable in most of the tests.

A concerted effort is necessary on the part of industry and others to ex-

tend present procedures and to develop new procedures for improved measurement of refinery contaminants. Wide dissemination of the findings would go far to bring to a focus the scattered knowledge in this field. Serious application of the research findings would hasten effective pollution control.

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PLAN EARLY

Now is the time to mark the calendar and begin plans to attend the 31st Annual Meeting of the Federation of Sewage and Industrial Wastes Associations in conjunction with the Michigan Sewage and Industrial Wastes Association. Reserve October 6–9, 1958, for the Sheraton-Cadillac Hotel, Detroit, Michigan, and expect to see all your old friends and meet many new ones.

UNDERGROUND WASTE DISPOSAL *

By William B. Black

Underground Surveys, Incorporated, Rockford, Ill.

This paper deals with pumping industrial wastes through deep wells drilled for this specific purpose into carefully tested rock horizons far underground.

Pumping fluids into the rock strata deep underground is not a new idea. More than 40 years ago it was demonstrated in the Pennsylvania oil fields that large quantities of water could be pumped into the tight sandstones, which contained crude oil, and thus flood out additional barrels of oil through other wells drilled nearby. Since that original discovery, many men have worked to understand the forces involved and to invent techniques to control and predict this underground flood.

Most of the information about pumping into underground rock strata has been developed in the geological field. From various geological studies considerable data have been accumulated about the movements of fluids underground. This knowledge has become of considerable interest to those concerned with the disposal of liquid wastes.

Pumping of industrial wastes underground also is not new. In Michigan two of the underground strata of porous sandstone, namely the Travers and the Sylvania, have been found satisfactory for industrial waste disposal. State authorities permit oil refineries, chemical plants, and pharmaceutical plants, to name a few, to use these formations for a variey of industrial wastes, both organic and inorganic. Oil field brines also are pumped into these formations in Michigan to avoid pollution of surface streams or of the fresh water underground. Texas, Arkansas, Kentucky, and California also have similar deep well waste disposal procedures in operation. In each case these disposal areas lie well below the lowest levels of fresh water and are completely isolated above and below by layers of impervious rock.

Rock Strata Testing

The new part of underground waste disposal is the discovery, in recent months, of a way to test these underground rock formations in advance of any injection of wastes. This test makes certain that the waste waters will be controlled, that they will not interfere with valuable underground fresh water, and that they will not create a hazard for surrounding property, either now or in the years to come.

This testing technique opens a field for solving difficult pollution problems. Until now, the deep waste disposal wells have been confined to the oil-producing areas and to underground rock strata containing salt water. Most industrial plants are outside of these areas. The testing procedure, however, can be applied at almost any location on the continent where porous rocks exist underground.

Figure 1 shows a typical cross section of the earth's crust. A great part of this country is underlaid by alternate layers of sandstones, shales, limestones, and clays in varying thicknesses and compositions. Some of these formations extend for miles and are hundreds of feet thick in places.

* Presented at the 1957 Annual Meeting, Florida Sewage and Industrial Wastes Assn.; Jacksonville, Fla.; Nov. 11–13, 1957.

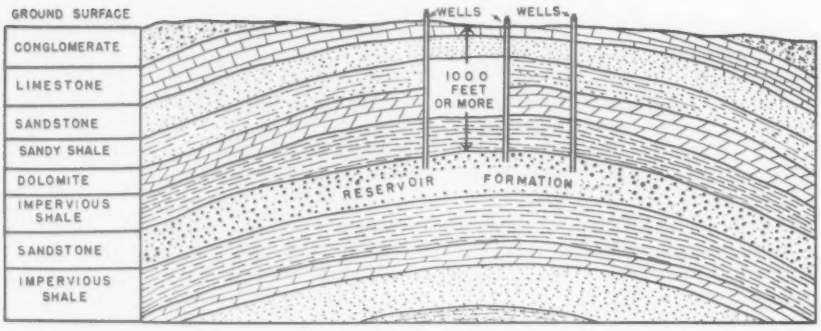

FIGURE 1.—Typical cross section of earth's crust.

Others extend only a short distance. Some pinch out here and there and reappear miles away. Most of the continent has been covered by oceans many times in the billions of years of history. The sandstones and limestone rocks forming the present source of oil probably once were beaches and sand bars in these oceans.

There is some visible evidence of these strata as shown by the ocean beaches. Some beaches show large and loose sand grains and others fine grains; some contain small pebbles, while others display white sand, and yet others are filled with shells. This same variety is present underground.

Steps in Testing

In order to take advantage of the desirable underground formations it is now possible, with modern engineering, to utilize the following steps in the exploration of potential waste disposal strata:

1. Make a fact-finding study of the wastes from an industrial plant, as is done for a conventional waste treatment installation.

2. Make a careful study of the underground rock formations nearby.

3. Make a laboratory compatability test of the reaction between the waste materials and rocks similar to those to be found deep underground. This will show whether these waste materials can be safely stored in the rocks.

4. Drill one or more test wells near the plant location to obtain samples of actual rocks. In the laboratory these samples also can be tested to find which of the rock strata are possible reservoirs, and how effective will be the barriers which confine the wastes in the proper place.

5. Test the rock formations penetrated by the test well, using harmless fluids similar in viscosity to the waste materials, for tightness, capacity, injection rate, and flow characteristics. From these data can be calculated daily capacity, pump pressures required, extent of waste travel underground in a given time, and factors of safety.

Benefits and Precautionary Measures

These procedures provide the basis for the economics of the system, the construction cost, the daily maintenance, and the depreciation cost. From these figures a decision can be made as to whether this or another type treatment plant should be constructed.

In all of this work extreme care is given to the supply of fresh water underground. The test well is carefully cased and sealed so that nothing can get into the fresh-water supply

and none of the fresh water can leak out. Where corrosive waste materials must be pumped underground, double liners of impervious material are used, and the liners are inspected regularly. The disposal rock formation itself also is sealed underground to prevent passage of waste material to any other formation. Continuous flow and pressure recording instruments give evidence of the success of the disposal operation, and automatic control of waste disposal is possible in some cases.

Disposal Potential

It is encouraging to note that wastes of many types can be put underground. Modern oil production fracturing techniques make it possible to split open the rock layers, at a given point, and hold them open under pressure while fluids containing considerable volumes of matter in suspension are pumped into this newly created shelf space. Since these storage rocks are overlaid by many feet of shale, clay, or other plastic material, this underground fracturing makes no disturbance or upheaval on the surface. Underground fracturing also will increase the capacity of the average disposal well, and make possible the storage of thousands of gallons per hour, day after day, and year after year, and still keep all of these wastes confined to a few acres. Forty million gallons per acre is a reasonable estimate of total storage capacity.

Heretofore the discussion has been about industrial plant wastes, both organic and inorganic, from many different sources. However, this procedure has broader potentialities. There is some evidence that atomic energy wastes can be handled in this manner, and in this connection a word of caution is advisable. Before waste material of any type is put underground, a careful and thorough test of the operation should be made, both in the laboratory where actual waste materials are forced through the reservoir rock samples under full pressure, and in the field wells where harmless fluids are forced into the reservoir rocks themselves under high pressure. Only after these tests are proved satisfactory should any public announcement be made that a waste disposal project is under way. The public generally is sensitive to information about underground disposal of radioactive wastes in particular and, to a certain extent, about any wastes. It is frequently believed that one manifestation of such underground pumping might be spontaneous spouting of harmful materials from the earth's surface. The truth is that there is no danger of escape of this waste material if proper precautions are exercised. Therefore, one major aspect of underground disposal consideration is public education.

Costs

Construction costs of deep well waste disposal systems vary widely, depending on depth of wells, type and volume of waste fluids, character of underground rocks, and amount of pretreatment required. One industrial installation at Victoria, Texas, drilled two wells about 4,800 ft deep for disposal of some 9,000 gph of waste brine, and reported construction costs in excess of $250,000.

Operating costs generally are rather low. Using an estimated electrical cost per kwh of 1 cent and a volume of 500,000 gal per 24 hr, approximate costs are estimated for a typical installation as follows:

Operation	Cost ($ per day)
Pumping expense	80
Maintenance of equipment	5
Replacing corrosion damage	10
Total	95

With the addition of costs of pretreatment, if any, and engineering supervision, there is still room to keep operating costs below one-tenth of a cent per gallon. On smaller volumes the costs probably would be higher

than this example. Since one well can service many acres, life expectancy per well would normally be several years. As a result amortization costs are reasonable.

Other Possible Uses

One of the interesting possibilities for underground disposal is for effluent from municipal sewage disposal plants. As an example of one ramification, in Midland, Texas, one of the oil companies has arranged to purchase these waters from the city and will pump them deep underground to flush out more oil.

Another interesting phase of underground fluid injection is storage of fresh water. From there it can be recovered easily and quickly whenever it is needed. Underground freshwater storages are expected to become common. Data from some currently in use indicate losses far less than the losses due to evaporation from a surface reservoir, and there are no problems of contamination, silting, and weed growth. These underground water reservoirs can accommodate excess rainfall and store it as long as desired. Construction costs for drilling wells may not be greater than the cost of a watershed and a dam because these wells generally will be rather shallow. Pumping water underground has proved effective in reversing the depletion of the ground water table and in controlling the inroads of brackish water along the seacoast.

It is predicted that there will be other beneficial uses of underground fluid injection not yet explored.

Summary

It is not intended to convey the impression that underground fluid injection is a panacea for all waste disposal problems. Rather, it is felt that this development is one more tool to be used by engineers when economic conditions are favorable.

Based on data at hand, however, it is indicated that underground disposal of industrial wastes can be a practical method which should be given serious consideration.

CLAY PIPE RESEARCH

On April 15, 1958, the National Clay Pipe Manufacturers' Association dedicated a completely new, modern research laboratory at Crystal Lake, Ill. The new facility is named, "The National Clay Pipe Manufacturers, Inc.—D. M. Strickland Research Laboratory," in honor of the past president who for many years headed this association.

The new laboratory is engaged in research aimed at numerous new developments and improvements in clay pipe and jointing methods.

OXYGEN DEMAND OF THE LOWER FATTY ACIDS*

By P. E. Gaffney and H. Heukelekian

Consistent and reliable BOD values for pure organic compounds would be highly desirable from the standpoint of industrial waste treatment. Knowing the quantity of chemical present in a particular waste, it would be possible to calculate the BOD load imposed by that chemical on the treatment process if a reliable value were available.

The BOD values for many organic compounds previously reported in the literature (1) show considerable variation. This is especially true of the fatty acid group where, for example, the 5-day BOD af acetic acid ranges from 0.11 to 0.88 part of O_2 consumed per part of compound.

In attempting to develop more consistent and reliable BOD values for the lower fatty acids, it became necessary to study the various factors involved, in order to standardize and control the oxygen uptake measurement. The factors studied with respect to their effect on the BOD of acetic acid were as follows:

1. BOD method employed.
2. Cation to which the fatty acid radical is attached.
3. Nitrogen and phosphorus concentration in the dilution water.
4. Nitrogen source.
5. Acid concentration.
6. Quality and concentration of seed.

The data concerning the effects of nitrogen and phosphorus concentration and nitrogen source have been presented in a separate publication (2). The errors in observed BOD due to nitrification were eliminated by maintaining the expected BOD: N: P ratio at 100:5:1 or by substituting nitrate as the nitrogen source in the dilution water. Once these factors were brought under control, it was possible to extend the study to other members of the fatty acid group and to obtain reliable BOD values for these.

General Procedure

Three types of BOD measurements were used—the standard dilution, jug dilution (3), and Warburg method, which can be used for concentration ranges of 2 to 8 ppm, 6 to 20 ppm, and 100 to 10,000 ppm, respectively.

To maintain all data on a comparable basis, acid concentrations are expressed as the concentration of oxidizable organic radical, and BOD results are presented (Table I) as parts of oxygen consumed per part of oxidizable organic radical.

In all tests where acid concentrations of 100 ppm or more were used, and only in such instances, the pH was adjusted to 7.0 prior to contact with the seed material. The oxygen demand of seed material was subtracted from the observed BOD in all cases. When studying high acid concentrations, it was necessary to use the fatty acid salt in order to maintain favorable pH conditions. Thus, it became necessary to determine if the cation employed has any effect on the oxygen demand of the acid radical.

In Table II are shown the results of one experiment where 8.0 ppm acetate in combination with four different cations were tested by the standard dilution method. Ten replicates were run with each cation.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University. Presented at 132nd National Meeting, American Chemical Society; New York, N. Y.; Sept. 8–13, 1957.

TABLE I.—Effect of Method on 5-Day BOD of Acetate

Method	Acetate (ppm)	5-Day BOD (parts/part)[1]				No. of Samples
		Min	Max	Avg	Avg Dev.	
Std. dilution	2 to 8	0.68	0.80	0.76	±0.03	9
Jug dilution	6 to 20	0.69	0.88	0.77	±0.06	13
Warburg	100 to 10,000	0.66	0.77	0.74	±0.03	7

[1] Parts O_2 consumed per part of acetate.

The results show that these cations have no differential effect on the BOD of acetate; hence, NaOH was arbitrarily chosen as the neutralizing agent for high fatty acid concentrations.

The results of a study of the effect of sewage seed concentration on the 5-day BOD value and length of lag period observed in the oxidation of high acetate concentrations are given in Table III.

TABLE II.—Effect of Cations on the 5-Day BOD of Acetate

Cation	5-Day BOD (parts/part)[1]			
	Min	Max	Avg	Avg Dev.
H	0.79	0.82	0.80	±0.01
Na	0.75	0.81	0.79	±0.01
K	0.74	0.79	0.77	±0.01
Ca	0.75	0.80	0.78	±0.01

[1] Parts O_2 consumed per part of acetate.

TABLE III.—Effect of Sewage Seed Concentration on the 5-Day BOD and Length of Lag Period with 100 to 10,000 ppm Acetate

Acetate Conc. (ppm)	Sewage Conc. (% by vol.)	Food:Seed Ratio	Lag Period (days)	5-Day BOD (parts/part)
100	0.1	1,000:1	1	0.76
1,000	0.1	10,000:1	1	0.74
10,000	0.1	100,000:1	5	0.03
10,000	1.0	10,000:1	5	0.10
10,000	100.0	100:1	5	0.12
100	1.0	100:1	1	0.76
10,000	—*	—*	—*	0.76

* 10 per cent adapted seed.

It was found that with up to 1,000 ppm acetate the established values of parts of oxygen utilized per part of acetate were obtained using as little as 0.1 per cent sewage with a lag period of one day. This is also shown in Figure 1. Adaption, through successive transfers of seed material with new acetate preparations, was necessary to develop a seed capable of efficiently oxidizing 10,000 ppm acetate (Figure 2).

Even where the food: seed ratio was held constant in one experiment using the same sewage as seed, the 5-day lag along with a low BOD value was still observed with 10,000 ppm acetate. This 5-day lag period was not always observed, however, because some sewages were able to oxidize 10,000 ppm after a one-day lag.

Large variations may be expected in length of lag period and 5-day BOD of the organic acids, due to a difference in sewage source or sampling time.

Table IV shows that with 10 per cent Highland Park sewage and 10,000 ppm acetate, the lag periods ranged from 1 to 5 days and the 5-day BOD from 0.06 to 0.77 parts per part. With 100 per cent Highland Park sewage the lag varied from 3 to 5 days, and the 5-day BOD from 0.12 to 0.64 parts per part. The 10 per cent Bound Brook sewage gave only a one-day lag and a 5-day BOD of 0.77 parts per part.

Ten per cent Bound Brook sewage

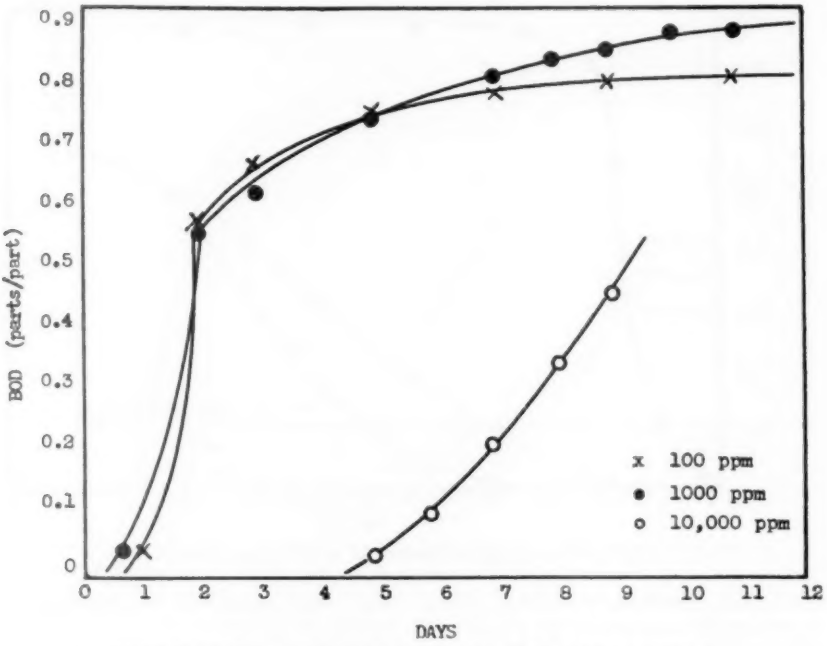

FIGURE 1.—Oxygen demand of 100, 1,000, and 10,000 ppm acetate.

and 10,000 ppm valerate gave a 5.5-day lag and a 5-day BOD of 0.06, as compared with a 2-day lag and a BOD of 1.34 obtained with 10 per cent Highland Park sewage.

It is concluded that reliable and expected oxygen demand values cannot be consistently obtained with 10,000 ppm organic acid substrate using an unadapted sewage as seed.

The effect of adaptation of sewage seed with successive transfers on the oxygen demand of 10,000 ppm of acetate, butyrate, and valerate is shown in Figures 2, 3, and 4.

Guided by the information obtained

TABLE IV.—Effect of Sewage Variations in Source and Sampling Time on the 5-Day BOD and Lag Period Observed with 10,000 ppm Acetate and Valerate

Acid		Sewage Conc. (%)	Source[1]	Date Obtained	Lag Period (days)	5-Day BOD (parts/part)
Conc. (ppm)	Type					
10,000	acetate	10	HP	8/14/56	5.0	0.06
10,000	acetate	10	HP	9/13/56	1.0	0.72
10,000	acetate	10	HP	7/5/56	1.5	0.77
10,000	acetate	10	BB	5/29/57	1.0	0.77
10,000	acetate	100	HP	2/11/57	5.0	0.12
10,000	acetate	100	HP	3/4/57	3.0	0.64
10,000	valerate	10	BB	5/29/57	5.5	0.06
10,000	valerate	10	HP	7/15/57	2.0	1.34

[1] HP = Highland Park, N. J.; BB = Bound Brook, N. J.

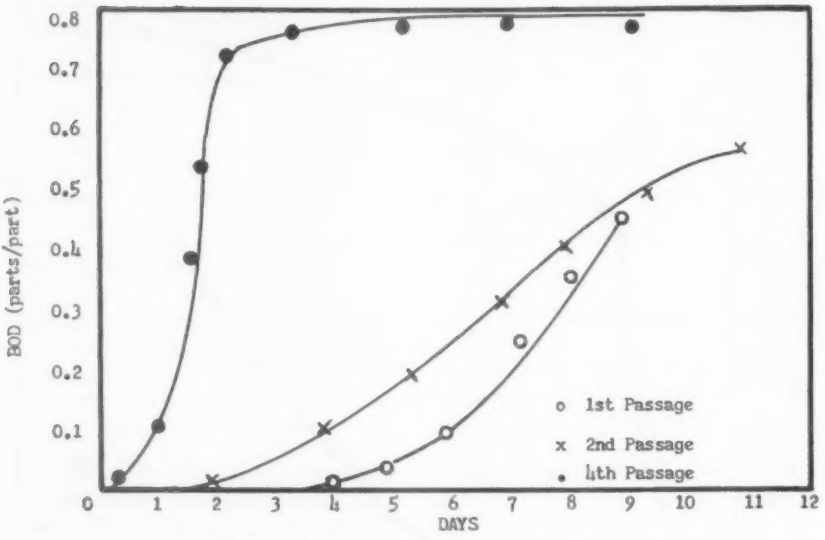

FIGURE 2.—Oxygen demand of 10,000 ppm acetate.

from these preliminary studies, it was then possible to measure the 5-day and 20-day BOD values of some of the other fatty acids.

In all cases, nitrate was supplied as the nitrogen source in order to prevent nitrification, and the BOD: N: P ratio was maintained at approximately 100: 5: 1.

The 5-day and 20-day BOD values for the fatty acids studied are given in Table V. Included also in this table are the theoretical oxygen demand (TOD) values (based on com-

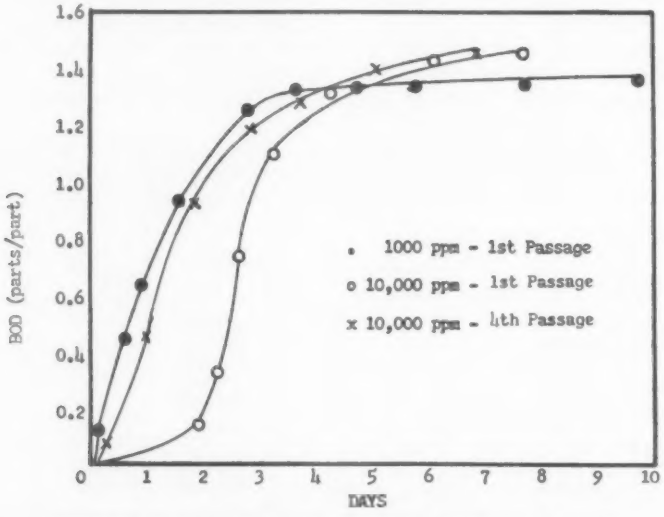

FIGURE 3.—Oxygen demand of 1,000 and 10,000 ppm butyrate.

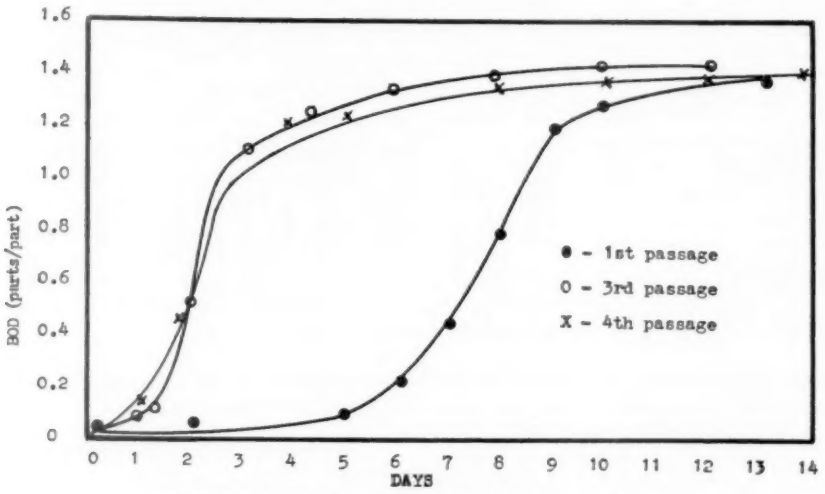

FIGURE 4.—Oxygen demand of 10,000 ppm valerate.

plete chemical oxidation to CO_2 and H_2O), the 5-day values as per cent of the theoretical value, and the 5-day values as per cent of the 20-day value.

Table V shows that the 5-day BOD of the lower fatty acids (excluding caprie) is equivalent to an average of 67 ± 3 per cent of the theoretical oxygen demand based on complete chemical oxidation to carbon dioxide and water. The caprate under these circumstances formed an emulsion, which most likely rendered the compound less available for biological oxidation than if it were completely soluble. This compound will therefore be considered among the "higher" fatty acids, which will be the object of future investigations.

The 5-day values given in this table for all the acids are equivalent to an average of 91 ± 4 per cent of the 20-day value.

Because the observed 20-day value was arbitrarily called the "ultimate," it was desirable to compare this observed value with a calculated *L*-value obtained by one of the common methods. The "moments" method (3) was used to calculate the *k*- and *L*-values for the available fatty acid curves. Some difficulty was experienced at first in applying this method to these pure organic compounds. The method is

TABLE V.—5-Day and 20-Day BOD Values of Some Lower Fatty Acids

Acid	Theoretical Oxygen Demand[1] (parts/part)	BOD (parts/part)		Ratio (%)	
		5-Day	20-Day	$\frac{\text{5-Day}}{\text{TOD}}$	$\frac{\text{5-Day}}{\text{20-Day}}$
Acetic	1.10	0.72–0.77	0.78–0.82	66–70	92–94
Propionic	1.50	1.00–1.10	1.11–1.26	62–73	87–90
Butyric	1.80	1.30–1.40	1.42	72–78	92–99
Valeric	2.04	1.28–1.35	1.44–1.54	62–66	88–89
Caproic	2.21	1.46	1.68	66	87
Caprylic	2.44	1.46	1.66	60	88
Capric	2.60	1.19–1.40	1.20–1.41	46–54	99

[1] Parts of oxygen per part of oxidizable radical.

TABLE VI.—*k*- and *L*-Values for the Lower Fatty Acids

Acid	No. of Samples	Calculated *k*			Calculated *L*			Observed 20-Day[1]		
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Acetate	3	0.18	0.21	0.19	0.83	0.87	0.84	0.78	0.82	0.81
Propionate	3	0.20	0.31	0.26	1.13	1.26	1.21	1.11	1.25	1.16
Butyrate	5	0.16	0.29	0.25	1.28	1.47	1.38	1.25	1.42	1.33
Valerate	3	0.18	0.31	0.25	1.41	1.49	1.45	1.47	1.48	1.47
Caproate	3	0.19	0.24	0.22	1.20	1.74	1.42	1.15	1.68	1.36
Caprylate	1	—	—	0.26	—	—	1.66	—	—	1.66
Caprate	1	—	—	0.24	—	—	1.29	—	—	1.20

[1] Parts of O_2 per part of oxidizable organic radical.

based on the assumption that a sewage oxidation curve follows, on the average, a unimolecular equation.

In attempting to calculate *k*- and *L*-values for these curves by adhering strictly to the moments method, much difficulty was encountered because readings within the lag periods were included in the calculations. This resulted in *L*-values that in most cases significantly exceeded even the theoretical oxygen demand value.

By eliminating the lag periods from the calculations and by establishing a new point of origin on the curve, these difficulties were overcome. The new point of origin was obtained by drawing a straight line along the steepest part of the curve and continuing this line to the time scale. The point of origin was then taken as the nearest one-half day to the left of the intercept of this line with the time scale. Calculations were then made considering this new point of origin as "zero days" and reasonable *L*-values were obtained which compared well with the observed 20-day value. Table VI shows the minimum, maximum, and average observed and calculated *k*- and *L*-values for the acids studied. These represent the results of tests where only 10,000 ppm of the acid was used and where a 20-day value was observed.

The results show a good agreement in all cases between the calculated and observed ultimate values and the rates of oxidation of the fatty acids are comparable to those reported for sewage by Ruchhoft (4).

Summary and Conclusions

1. The sodium, potassium, and calcium salts of acetic acid give a 5-day BOD of 0.77 to 0.80 parts of oxygen per part of acetate. This indicates that these cations have no differential effect on oxidation of the fatty acid radical.

2. The standard dilution, jug dilution, and Warburg methods give comparable BOD results with a given compound.

3. Sewage quality has a great effect on the oxygen demand of 10,000 ppm of the organic acids. The volume of sewage used as seed did not have such a pronounced effect on the oxygen demand. Many variations in length of the lag period and 5-day BOD value were observed with 10,000 ppm acetate and valerate. These variations were due primarily to differences in sewage source and sampling time.

4. Consistent and reliable BOD values cannot be obtained with 10,000 ppm of fatty acid using an unadapted sewage as seed.

5. In cases where a long lag period is observed in the oxidation of high concentrations of the fatty acids, it is possible to develop an "adapted seed" through successive transfers of seed material. This procedure greatly reduces the lag period and yields 5-day BOD values corresponding to those ob-

tained with lower acid concentrations.

6. The 5-day BOD values of the lower fatty acids in concentrations ranging from 2 to 10,000 ppm represent approximately:

(a) An average of 67 ± 3 per cent of the theoretical oxygen demand based on complete chemical oxidation to CO_2 and H_2O. This excludes the 5-day value for capric acid.

(b) An average of 91 ± 4 per cent of the ultimate oxygen demand based on direct measurement after 20-day incubation and on calculation by the moments method.

7. The average calculated k-values of 10,000 ppm of the lower fatty acids varies from 0.19 to 0.26 once any lag period has been eliminated.

8. Good agreement has been obtained between the observed 20-day BOD value and the L-value calculated using the moments method because nitrate was supplied as the nitrogen source, thereby preventing nitrification from occurring.

Acknowledgment

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REVISED FSIWA SAFETY MANUAL NEARLY COMPLETE

Since the October Federation Meeting, final comments have been made by reviewers on the revision of Federation Manual of Practice No. 1, "Occupational Hazards in Sewage Works Operation." The original edition, issued in 1944, was reprinted with an additional appendix in 1952. This edition has been out of print for over a year.

The manual is in final draft stage and is scheduled for printing within the next two months. Its availability and price will be announced in THIS JOURNAL.

The revision has been prepared by the Federation Safety Committee with J. J. Wirts as Chairman. For this project, the group has worked as a subcommittee of the Committee on Sewage and Industrial Wastes Practice, M. M. Cohn, Chairman.

The new edition will include the latest practices in safety methods which may affect the operation of sewage and industrial wastes treatment plants. It is hoped that this publication will satisfy the demand for a current manual in this most important aspect of works operation and maintenance.

Stream Pollution

ECONOMICS OF POLLUTION CONTROL

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In recent years increasing attention has been focused on the way in which the socio-economic-political process determines permissible pollution (1). Furthermore, the methods used by water pollution agencies to obtain control have been subjected increasingly to debate and discussion (2)(3). Also, the question has been raised as to whether the pollution control end should be obtained by stream classification, stream standards, effluent standards, or no standards. Lee (4) has concluded:

> "Many states now favor a method of stream classification whereby, after adequate public hearings, the water pollution control authority allocates streams, or parts of streams, for certain best uses and designates the standards required for those uses. This has the advantage of insuring that everyone knows what is required, but it has the disadvantage of making it difficult to raise standards to a higher classification. Effluent standards are easiest to enforce because this method eliminates the need for extensive stream surveys though it may fail to take full advantage of the self-purification powers of a stream. Effluent standards impose the same requirements on a company fortunate enough, or wise enough, to locate on a large stream as are required of a competitor located on a small stream or brook. Stream standards, either with or without formal classification, are much to be preferred over effluent standards."

In this paper an attempt is made to emphasize that there are both benefits[1] and costs associated with pollution, that an optimum solution to the problem of pollution control cannot be reached without taking into account both, balancing at the margin incremental benefits against incremental costs.

By way of stimulating thought on a complicated and difficult subject, an alternative approach to pollution control is advanced which has taken explicitly into account the cost of pollution, and permits waste producers freedom to solve at minimum cost their own waste disposal problems. Although the idea of a penalty function may be somewhat utopian and impractical, it permits attention to be focused on a few of the economic issues involved in control standards.

Existing Control Plans

In economics there is a tendency to be suspicious of either fixed pollution standards or stream classification standards, because it is doubtful, if not unreasonable, to suppose that a pollution control authority will have sufficient information to determine (a) the highest use to which a limited amount of water can be put, (b) the optimum degree of pollution, or (c) the optimum degree of waste treatment which stream classification, stream standards,

[1] Participants at the 1953 FSIWA Industrial Wastes Forum were generally agreed that waste disposal constitutes one of the legitimate uses of a stream and that the natural self-purification capacity of a stream is an economic asset which should not be wasted. It was noted, however, that most people seem to feel that waste disposal should not interfere in any way with other uses of water; that all other uses should have priority over waste disposal.

and effluent standards, respectively, presume the authority can determine.

Can a pollution authority reasonably be expected to know the value of water to all users, individually and collectively: domestic, industrial, agricultural, navigational, recreational, etc.? Essentially stream classification presumes that the demand [2] for the value of water in every competing use is sufficiently well known that the regulatory commission can allocate rationally or determines its best uses. At present economists know little about the nature of the demand for water in even the simplest and most common uses, such as domestic,[3] agricultural,[4] and power development.[5] Virtually nothing is known about the nature of the industrial, recreational, and aesthetic demands for water, the interdependence of the various demands, or the relationship between water quality and demand.

Standards

From an economic point of view, at least, it seems clear that a regulatory commission in establishing stream classifications will be making complex judgments as to the value or the nature of the demand for water in a great many competing and interdependent uses. These demands are not well known. Attainment of an optimal classification in the first place might well be a matter of chance; if Lee is correct in alleging that classifications once established are difficult to change, it would seem even more unlikely that any classification system could be expected to remain optimal.

Towne (5) has emphasized that the growing demand for water has occasioned a need for standards sufficiently flexible to accommodate future changes in social and economic conditions. These changes are often unpredictable.

The fixing of stream standards, on the other hand, must also be subjected to criticism. Is it likely that a regulatory commission will have sufficient information with respect to both the value of polluting and its social cost to set an optimal rate of permissible pollution? Is it likely that the optimal rate would be independent of the time of day, the season, hydrologic variables, economic change, and technological developments? The first question raises a doubt as to whether a regulatory commission can reasonably be expected to know what the optimum rate of pollution is; the second question raises a doubt as to whether the rate is sufficiently constant as to be thought of in terms of a standard which can be established prior to changing circumstance.

Value or Demand

With respect to assessing the value or demand for the privilege of polluting, it must be confessed that nothing is known save that the true demand is never greater than the alternative cost of disposing of waste materials by other means. At some point, the demand to pollute can be expected to fall below the alternative cost of waste disposal, because it is unlikely that successive units of pollution will always be valued as greatly as preceding units. Although considerable resources have been used to pull together the costs of waste treatment

[2] Value in the demand sense can be thought of as the maximum amount people would be willing to pay for the use of water in any amount or direction rather than forego the amount or use entirely.

[3] Such a study is now in the preliminary stage of derivation.

[4] A rather restricted study has been made of the demand for irrigation water (see "The Demand for Irrigation Water in the Ainsworth Area of Nebraska," unpublished Ph.D. dissertation by John Dawson, Dept. Economics, Univ. of Chicago; 1957).

[5] A more complex study, which considers not only the demand for irrigation water but also the demand for water at power installations, is being made. (See "Water Allocation in the North Platte and Platte Rivers," unpublished thesis prospectus by V. S. Hastings, Dept. Economics, Univ. of Chicago; Jan. 31, 1957.)

(6)(7)(8), nothing has been done to determine the point or rate at which the demand to pollute breaks away from the alternative cost of waste disposal.

Nevertheless, the demand side, even if it were known, is only half the solution to the determination of an optimum pollution rate; to arrive at a specific rate, one would need to know the social cost of each alternative pollution rate. Because a knowledge of the social cost of polluting is basic to any scheme for controlling or regulating pollution, discussion of the difficulty of obtaining this information is deferred until later. Suffice it to say that the idea of an optimal pollution rate is sufficiently complex to make it doubtful that any regulatory commission would have adequate information to determine it. Furthermore, the stochastic nature of hydrologic, economic, and technical variables makes it inadvisable to think of optimal pollution in terms of a unique rate. Sanitary engineers, such as Velz, have repeatedly emphasized that the self-purification capacity of streams is a function of a great many hydrologic and geographic variables (9)(10)(11).

Critical Evaluation of Standards

Fixing of effluent standards, if they are to be at all consistent with maximum social welfare, would entail on the part of a regulatory commission not only knowledge of the social cost of pollution, but also complete knowledge of the cost of disposing of waste products by other means. Essentially, the effect of imposing effluent standards on waste producers is to force them to bear a portion of the cost of waste disposal. If the effluent standards set by the regulatory commission are to be even approximately consistent with the ideal of cost minimization, all costs considered, that set of effluent standards must be selected which brings into equality the marginal (incremental) costs of disposing of waste by every relevant alternative means. For a uniquely optimum solution to be arrived at independently of an explicit consideration of demand, the marginal costs of waste disposal in every direction, including pollution, not only must equal, but also must be borne by waste creators.

It does not seem likely that the optimal set of effluent standards could be reduced to a unique standard that could be made applicable to every polluter without adjustments for the nature of his pollution demand, his location in relation to receiving waters, and the degree of economic development around him, unless one were prepared to accept a situation in which there would exist under- and over-utilization of purification capacity. One or the other, or both, would be the price that would be paid for simplicity and the appearance of a fair standard. It is also doubtful that the optimal set of effluent standards would be stable or constant with respect to the time of day, the season, and changes in hydrologic, economic, or technological variables.

The criticisms which an economist is forced to make with regard to stream classification systems, stream standards, and effluent standards can be summarized as follows:

1. While on an abstract level there is a correspondence between the three systems such that each system could be made to yield the same set of adjustments to the pollution problem, lack of information on the part of regulatory commissions and the rigidity of standards and classification systems, once imposed, make it unlikely that an optimal result would be obtained. Without a great deal more information than is currently available, a confident judgment cannot even be made as to which of the three methods would lead to the most optimal results.

2. Each of the three methods entails more regulatory information of an eco-

nomic character than is necessary to approximate desirable economic adjustments to the waste disposal problems.

Other Considerations

Because economic values are the most suspect and the most difficult for a regulatory commission to come by, greater consideration ought to be given to other pollution control alternatives. The penalty approach has among its virtues economy with respect to the kind of value information that is needed by a regulatory commission and excellent possibilities for built-in flexibility. Furthermore, as a by-product of the system, the penalties actually paid by the polluters yield information that could be used to assess benefits from stream regulation and the losses that would accrue if water were diverted to other uses. Whether the system would be practical from a technical, administrative, or political point of view is a question requiring further consideration. The suggestion is advanced primarily as a means of stimulating thought with respect to alternative ways of achieving the pollution control end. The sketchy detail in which the plan is presented can surely be modified, improved upon, and simplified to fit individual cases.

Penalty Approach to Pollution Control

Basic Philosophy

From a social point of view, the criterion which should be used to determine the optimal disposal of a given quantity of waste is that the real costs of waste disposal, all costs considered, be minimized. A necessary condition for obtaining a minimum is that costs be incurred in alternative disposal directions, such as waste treatment, stream regulation, and consideration of the effects of pollution until the incremental costs of waste disposal in every direction are equal. On general economic grounds, it can be assumed that a policy of cost minimization will lead to an optimum production of waste, provided waste creators are forced to bear the incremental cost of waste disposal. Such a policy would be consistent with the competitive ideal of marginal cost pricing.

There exists a great deal of evidence to indicate that the individuals and groups responsible for waste disposal do strive to adjust waste disposal inputs so that the cost of waste disposal is minimized. This is brought out by a large number of published articles reflecting interest in the cost of alternatives such as stabilization ponds, sludge pipeplines, combined treatment of domestic and industrial wastes, industrial waste recovery, re-cycling of waste water, overloading of treatment facilities, etc. The problem is that the cost of polluting can be shifted to someone else, hence need not be given the same consideration as other costs. If, however, a means were devised for estimating the real loss from pollution and a mechanism were created for collecting losses from polluters, it is reasonable to believe that waste producers and disposers would have sufficient incentive to adjust their resources so that, from an over-all point of view, there would be no pollution problem.

This is not to say that there would be no pollution. In fact, there might be a great deal more or less pollution, depending on the relative value to society of polluting and its relative cost. It would not necessarily mean that everybody, or even anybody, would be truly happy over the results, for there will always be those whose best interest would be served by zero pollution and those whose best interest would be served if the cost of polluting were zero. All that is hoped is that the penalty approach would lead to a better solution to the problem of waste disposal.

Mechanics of Execution

The philosophy underlying the penalty [6] approach to pollution control is that polluters should be allowed to pollute as much as they like, provided they are willing to pay the penalty or the cost of additional pollution. The penalty approach to pollution control is closely related to the approach suggested by Jacobs at the 1953 Industrial Waste Forum (13). The pollution control authority would have as its responsibility the determination and collection of penalties. The idea assumes that potential polluters, acting in their own best interests, will then strive to adjust their waste creation and disposal activities so that the net value associated with waste creation is maximized and the over-all real cost of waste disposal is minimized.

Related Factors

At a technical or engineering level, the penalty approach assumes that waste creators can be identified and that their contribution to the over-all pollution load can be measured. At the administrative level, the approach assumes that the added expense of administering the plan will be less than the social loss incurred by a less optimal plan. At a policy level, the approach assumes that penalties can be assessed which will be both politically acceptable to a majority of the citizenry, and will approximate the true cost of pollution. It is recognized that the invalidity of any one of these assumptions would be sufficient to render the penalty approach technically, economically, or politically unfeasible. For the purpose of this discussion, however, these possibilities will be ignored.

An important step in the construction of a penalty function is to develop concepts of pollution which can be functionally related to cost in a meaningful economic manner. The problem would be greatly simplified if pollution had only one attribute of economic consequence, or indeed if all wastes could be reduced to a measurable common denominator. Such is not the case, however; the cost or penalty associated with polluting must be looked upon as a net sum of the costs-benefits which are associated with attributes of waste products, such as odor, taste, suspended particles, organic matter, inorganic substances, heat, bacteria, etc.

At a first approximation, penalties can be tied directly to indexes of individual attributes of waste products; the penalty can then be thought of as a cost function of the attribute under consideration. In tying penalites to individual attributes of waste products, it should be borne in mind that the penalties associated with each attribute may not be independent of each other. For instance, fish can be killed by virtue of BOD loadings exhausting the available oxygen supply, or by the presence of toxic substances. The cost of a fish kill, however, should not be compounded by the number of attributes which could conceivably have been responsible for the killing, but rather it should be prorated among them or allocated to the most likely attribute.

Presumably, one would want to assess separately pollution penalties at all important points of consumptive use along the affected receiving water. At each point of consumptive use, the penalty could then be considered not only a function of the degree of pollution, but also a function of the duration of pollution in hours or days, the time of the day, and the season of the year in which pollution occurs. For instance, the presence of toxic substances in large quantities may not be sufficient to kill fish if their passage is of short duration. Once fish have been killed, the incremental cost of an extra

[6] The idea of attaching the word "penalty" to what in the economic literature is denoted as social cost, was borrowed from Romer (12).

day of polluted water may be negligible. With respect to seasonal variation in the penalty function, it is quite obvious that certain values (such as those associated with safe swimming) may not exist during the winter, hence would not be lost as a result of pollution.

To facilitate optimal adjustments to the waste disposal problem, penalty schedules should be constructed and posted in advance of the date at which they are to be made applicable. Flexibility and dynamicism can be introduced into the schedule by relating changes in the schedule to changes in real economic variables, such as population and industrial development at points of consumptive use. Provisions should be made, of course, for periodic review of the continuing applicability of the parameters used in constructing penalty schedules.

Collection and Distribution of Penalties

Initially the control authority has an option of determining a penalty function which will immediately affect the nature of waste disposal, hence the distribution of net income along the receiving water, or of determining a penalty function which will affect primarily only the future distribution of income.

A question which must be faced is whether to penalize polluters for the existing quantity of pollutant or to apply penalties only to incremental increases in pollution over and above present amounts. If an objective of control is to improve stream conditions, penalties would have to be attached to existing pollutants in order to make it in the interest of polluters to institute a higher degree of waste treatment. The effect of attaching penalties to existing pollution would be to increase the current cost of waste disposal and, if minimal cost adjustments occasion a smaller degree of pollution, to decrease the costs of pollution borne downstream.

Penalty Assignment

Any number of schemes could be devised for allocating or prorating a given total penalty to contributing polluters. An appealing device, however, is to allocate the total penalty in direct proportion to waste contributed and to allow any firm or agency to pollute in any amount, provided it expressed a willingness to abide by the rules. A license fee might also be assessed to cover the fixed administrative costs associated with measurement and assessment. The advantage of a penalty assessment in proportion to waste contributed, from the standpoint of an optimal allocation of the waste disposal asset of a receiving water, is that rights to pollute are not established which are or become independent of the value and cost of polluting. A price mechanism is created by proportional allocation which permits the competitive process to ration or put the self-purifying powers of a stream to their highest alternative uses, unimpeded by the costly transfer of legal, administrative, or institutionalized rights to pollute.

One of the difficult problems faced by a regulatory commission in implementing stream standards is allocating the designated capacity of the stream among polluters (14). Proportional penalty payment and freedom to become a polluter would remove the regulatory commission from the very trying and difficult job of rationing the very valuable right to pollute.

Penalty Collection

It is expected that the collection of penalties will pose a problem with respect to their ultimate distribution. If it can be demonstrated that the penalties collected represent substantial unrecoverable losses to individuals or organized entities, there would exist a justification for distributing penalties

received to those who are forced to bear the costs of pollution. If, however, the costs to individuals are small, if they have been deducted from income and property values prior to the implementation of a penalty system, or if they are ultimately borne by large groups and the public in general, there is a justification for regarding the penalties that are collected as a tax and distributing the net proceeds to affected municipalities to use as they see fit; the assumption being that the proceeds will be used by the municipalities in such a way that the losers from pollution will be ultimately compensated in terms of increased governmental services or a smaller tax bill.

The Measure of an Appropriate Penalty

Ideally, a penalty function should approximate the incremental social cost associated with a change in the pollution rate. From the standpoint of practical pollution control, however, it may not be of critical importance that the penalty function represents what an economist would consider the true costs involved. There is a sense in which the social costs of pollution can only be what a representative body politic (1), reflecting the conflicting interests of both polluters and those who are damaged by pollution, can in a compromising fashion agree the cost to be. Presumably, the pollution control authority in endeavoring to establish a penalty function would seek the advice of economists and engineers and would finally agree on a specific function only after extensive hearings at which all affected parties could be heard. In this section, an attempt is made to define costs of pollution and to discuss possibilities for measuring these costs in dollar terms.

In a general way, the penalties society pays as a result of pollution can be arbitrarily grouped into the following categories:

1. Increased water supply costs—domestic, agricultural, and industrial, including water transport and power facilities.
2. Fish and wildlife losses.
3. Recreational and aesthetic losses, including losses to swimmers, boaters, and nature lovers.

Water Supply Costs

Of all the losses from pollution, conceptually the easiest to measure are water supply costs. A good approximation of the losses from polluted waters can in this case be obtained by estimating the added cost of water treatment and plant cooling (if water has been polluted with heat) and by estimating the cost of maintenance, repair, and replacement due to increased corrosion. Engineering estimates of these costs are always relevant in assessing penalties unless the incremental costs of obtaining water supplies from an alternative source, such as wells or an unpolluted stream, is less than the costs incurred from pollution.

The only economic loss of an intangible nature associated with polluted water supplies is a change in quality which cannot be readily or economically corrected by proper treatment.

Fish and Wildlife Losses

The social loss from a reduction in commercial fishing is not as great as is often imagined, because much of the value associated with the consumption of commercial fish is exhausted by the resource cost incurred in obtaining the fish from their natural habitat. The alternative product which could be produced by fishermen and their invested capital in some other industry must be subtracted from the commercial loss resulting from either a kill or depletion in arriving at a net loss from pollution.

The value of sport fishing is more difficult to pin down, because there is

value associated with the act of catching fish which is not at all related to the consumptive value of fish. This value is fundamentally related to the willingness of fishermen to pay for the privilege of fishing. A license demand for the privilege of fishing can conceptually be thought of as a function of the expected catch, the kind of catch, the limit on the catch per person, the price of the license, and the relative price of substitutable activities, including the possibility of fishing elsewhere. Data on license fees could be used to obtain a rough estimate of the value foregone by sportsmen as a result of a fish kill.

Recreational and Aesthetic Losses

Of all the values destroyed by pollution, perhaps the most difficult to measure are recreational and aesthetic values. The measurement task, however, is not as hopeless as might be imagined. Economic theory suggests that a large part of the aesthetic and recreational value of a stream, or an area for that matter, is capitalized into private land values. By astutely appraising the value of land with and without the aesthetic assets of an unpolluted body of water, there is hope of obtaining a reasonable estimate of the penalty to assess against pollution.

There does exist a somewhat moot question, however, as to whether land set aside for public purposes is worth more or less than the price it would command in the market. The act of setting it aside would seem to imply that the land is worth more to the public than to private individuals. On the other hand, there is reason to believe that a large part of the recreational and aesthetic benefits from public lands is indirectly capitalized into private land values.

As a maximum, the recreational and aesthetic benefits lost from pollution can never be greater than the incremental cost of providing comparable or reasonable substitutes for benefits foregone; for instance, swimming pools can be substituted for beaches. In this case, not all the incremental costs of constructing a municipal pool should be charged to pollution, because a pool by virtue of its inherent safety may be a more desirable public asset.

If the methods which have been advanced for measuring intangible benefits are not appealing, there always exists an expedient political alternative. This is to put an array of alternative penalties or penalty functions on a ballot, let the citizenry and affected interests vote (knowing that whatever penalty they select must balance pollution losses against increased costs of waste treatment), and accept the average penalty vote as a measure of the social cost of pollution.

A By-Product of the Penalty Approach

A record of penalties paid, assuming a penalty system were actually put into effect, would provide economists with valuable information that could be used to assess both the benefits from low-flow regulation and the loss which would occur if water is diverted to a competing use, such as irrigation. Penalties paid, divided by a standardized measure of stream flow, could be used to generate a statistical demand for water as an agent of dilution. As a first approximation, the savings or benefits from low-flow regulation, for instance, constitute the difference between penalties that would be incurred during low-flow periods and the penalties that would be incurred during periods of high flow. The simple difference is approximate and not precise, owing to the fact that flow regulation may affect not only the cost of pollution but also the costs incurred in treating waste products by other means. An exact solution to either flow regulation or diversion is the difference between total waste disposal costs with and without stream regulation or dilution.

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12. Romer, H., "The Health Department's Role in New York Harbor Pollution Control." THIS JOURNAL, **28**, 12, 1495 (Dec. 1956).
13. Bloodgood, D. E., "1953 Industrial Wastes Forum." THIS JOURNAL, **26**, 5, 641 (May 1954).
14. Hess, S. G., "The Equitable Use of Streams." THIS JOURNAL, **26**, 1, 83 (Jan. 1954).

MEETINGS OF INTEREST

1958

May 5–7	**Thirteenth Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Purdue University, Lafayette, Ind.
May 18–24	**Inter-American Association of Sanitary Engineers,** San Juan, Puerto Rico. Enrique Ortega, Secretario General AIDIS, Associacion Interamericana de Ingenieria Sanitaria, Apartado de Correos 218, San Juan, Puerto Rico.
May 19–23	**Short Course on Safety Management Techniques,** National Safety Council, Chicago, Ill. Director of Industrial Training, National Safety Council, 425 N. Michigan Ave., Chicago, Ill.
May 25–29	**Liquid Scintillation Counting Conference,** Northwestern University (Technological Institute), Evanston, Ill.
May 26–28	**Fifth Ontario Industrial Waste Conference,** Delawana Inn, Honey Harbour, Ont., Canada. A. E. Berry, Ontario Water Resources Commission, East Block, Parliament Buildings, Toronto, Ont., Canada.
June 22–25	**American Institute of Chemical Engineers,** Bellevue-Stratford Hotel, Philadelphia, Pa. F. J. Antwerpen, Executive Secretary, 25 West 45th St., New York 36, N. Y.
June 23–27	**American Society of Civil Engineers,** Multnomah Hotel, Portland, Ore. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.

THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

1957 OPERATORS' FORUM *

W. D. HATFIELD, *Leader*

Superintendent, Sanitary District, Decatur, Ill.

This is the second of two sections of the forum and includes discussion on activated sludge, trickling filters, and stabilization ponds. The first section, dealing with grit chambers and primary settling, and sludge digestion was published in the April 1958 issue of THIS JOURNAL.

Activated Sludge

T. R. Haseltine, Partner, The Chester Engineers, Pittsburgh, Pa.:—I always enjoy talking about activated sludge, but I feel that many of the units we use to talk about it are so irrational they confuse us rather than help us to understand the subject. One of the most unfortunate units is that of expressing the loading in pounds of BOD applied per day per thousand cubic feet of aeration tank volume. I think this is meaningless. It makes no allowance for the weight of sludge carried in the tanks or the intensity of the aeration. An aeration tank without sludge is analogous to a filter without media. I believe that BOD loading should be expressed as pounds per hundred pounds of either total or volatile solids in the aeration system; and in applying this measure, consideration must be given to all of the solids in the aeration system. If there are separate sludge reaeration tanks, you must include these solids as well as the solids in the mixed-liquor tanks proper. If the plant is well-operated, there probably are not many solids in the final clarifiers; but there are certain proprietary devices that combine sedimentation and aeration in the same basin. Some of these have considerable sludge that is not in the aeration compartment, but this sludge must be considered in the amount of sludge in the aeration system. Obviously, the BOD input must include all the BOD going into the system (settled solids, supernatant solids, etc., but not the returned sludge).

Another time-honored, but misleading, unit is that of reporting air usage as cubic feet per gallon of raw sewage. Air requirements of the plant may depend on the number, type, and location of diffusers, the BOD input, the amount of BOD removed, the weight of sludge solids carried in the system, or the condition of that sludge. It certainly does not depend on the amount of liquid flowing through the tank. I believe that air usage should be expressed in two ways: (a) in cubic feet per pound of BOD removed, and (b) in cubic feet per day per pound of

* From transcript, 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

volatile solids carried in the aeration system.

A third unit that is somewhat misleading is the aeration period. We used to calculate the aeration period on the basis of the mixed liquor flow, including the returned sludge. More recently the tendency is to calculate on the sewage or incoming waste flow only. Actually, neither of these periods is of much significance. Activated sludge has the ability to quickly absorb or otherwise remove most of the pollutants from the incoming waste and store them for synthesis into additional sludge floc. The time available for synthesis is the important factor. If it is too short, the sludge becomes glutted and loses some of its adsorptive power. If it is too long, excessive amounts of sludge are destroyed by endogenous respiration and oxygen consumption is increased without a corresponding reduction in BOD. This time is a function of the previously discussed BOD to solids loading and is entirely independent of either the sewage, the mixed liquor, or the aeration period. However, a minimum mixed liquor period of 30 min or more is probably desirable in order to assure adequate time for the sludge to absorb the BOD from the incoming waste.

Finally there is the matter of return sludge volumes. By custom, we express the volume of return sludge as a percentage of the sewage flow, but it would be more logical to express it as a percentage of the mixed liquor flow. Activated sludge requires oxygen in order to maintain its activity. It cannot obtain an adequate supply in a final clarifier or when traveling through a long return sludge line. Such periods must be kept at a minimum. However, some time must be allowed for the sludge to settle, probably at least 30 to 60 min. Therefore, the theoretical minimum return sludge rate expressed as a percentage of the mixed liquor flow would equal the volumetric percentage of sludge in a sample of the mixed liquor after it had stood quiescently for a similar period of time. Practically, the rate should be somewhat greater because of the disturbances that take place in the clarifiers which do not take place in the laboratory. Since this minimum rate of return is dependent on the amount and settling characteristics of the mixed liquor solids, as well as the fluctuating flow of incoming sewage, and because excessive operating attendance would be required to constantly maintain the minimum rate, it is much simpler to return at a considerably higher rate and thus reduce operating costs while still avoiding undue retention of the sludge in clarifiers and sludge return lines.

Many small treatment plants operate with return sludge rates in excess of 100 to 150 per cent of the sewage flow —that is 50 to 66 per cent of the mixed liquor flow. Some larger plants have operated with returned sludge rates averaging 70 to 85 per cent of the sewage flow. This is equivalent to 40 to 46 per cent of the mixed liquor flow.

Richard H. Gould, Greeley & Hansen, Engineers, Chicago, Ill.:—While I was in New York, we did have quite a lot of experience with activated sludge covering a period of about 25 years. During that time we built six complete treatment plants using step aeration, and three others were built for the high-rate process only. Now, in the past 20 years, all those plants were designed and operated on the sludge age theory.

It was recognized that in 30 min you take out practically all the impurities and they become attached to the activated sludge. It was also recognized that it took about 3 to 4 days under aerobic conditions for those freshly abstracted materials to acquire good settling properties. Now these facts were used to develop step aeration, but apply equally well to standard activated sludge.

With reference to peak loadings, it

has been considered that 30 lb of BOD per thousand cubic feet of aeration tank capacity is a pretty fair figure, under standard procedures. It is understood from the literature that at Austin, Tex., the so-called biosorption process has run at 140-lb loadings. It is noted, however, that the sludge age was 3½ days, and the contact time of the sewage was 37 min. Now, that is about as close as you can get to the fourth pass addition in step aeration. At Peoria, Ill., even higher loadings were reported. But here, in addition to re-aeration, Kraus added heavy sludge from anaerobic digestion. The sludge age, it is believed, was from 3 to 4 days. Step aeration has worked well at loadings of over 60 lb.

I agree with Ted Haseltine that aeration tank loadings have no significance in themselves unless they are related to the process and other plant elements. There is no apparent limit as far as biology is concerned; there are, however, very definite limits in the amount of air that can be forced into the sewage in a limited area; and there are other limitations in plant design and other facilities.

The final settling tanks are just as important as the aeration tanks. Failure to understand the influence of density currents can result in loss of capacity in the final tanks and in the complete process.

The less complete process of high-rate activated sludge operates under low sludge ages of 0.2 to 0.5 days. The influence of soluble BOD is of great importance. The high-rate process is not as stable as the standard process and its control is delicate. Its effectiveness on some sewages may be limited.

Clair N. Sawyer, Professor of Sanitary Chemistry, Massachusetts Institute of Technology, Cambridge, Mass.: —I would like to comment on the question that Ted Haseltine raised in regard to rate of return sludge. This matter of how much sludge you are going to return, etc., is a very intriguing one; and in European practice they have perhaps outdone us in this respect. I know in some parts of Holland they claim a return sludge rate of 400 per cent. I don't know the basis of calculation, but I accept the 400 per cent. It seems to me we need to do a little thinking here at this particular point. What are you accomplishing by a high rate of return sludge? Fundamentally, of course, you are diluting the concentrated waste in order to get the substrate level down to a point where the bacteria are not stimulated to any unusual or unwanted degree. That is one way of accomplishing it. Exactly the same thing can be accomplished by bringing the sludge back at a normal rate, then adding the raw sewage down along the first passage of the aerating step a little here and there. In this way you get the same effect—you keep the substrate level down to a point where you do not get unusual stimulation of these organisms.

W. W. Mathews, Superintendent, Gary Sanitary District, Gary, Ind.: —In carrying out a test (described in "Treatment of Ammonia Still Wastes by the Activated Sludge Process," THIS JOURNAL, **24**, 2, 164 (Feb. 1952)) at the Gary treatment plant, varying rates of return sludge were used with increased loadings. As the organic load increased from increased amounts of still wastes received, the rate of return sludge was also increased. Air supply and mixed liquor solids concentration were also increased with increased loadings. It was discovered that, with rates of return in the 30 per cent ranges, the DO in the return sludge (where it was picked up by the return sludge pumps at the secondary manholes) might vary from 0.4 to 0.8 ppm. In the 60 per cent rates of return, the DO averaged 2 ppm. Through the courtesy of several operators, data were obtained on DO of return sludge at other plants. The

data ranged from zero to 2 ppm DO. Rates of return varied from 18 per cent to 100 per cent. This last rate was not commonly used but returns up to 70 per cent at this plant were often used. Checking the data it was found that, in this group of plants, those that returned at rates of 45 per cent or higher reported the DO in the return sludge at 2 ppm.

Less air was required at these plants to reduce 1 lb of BOD than at those plants employing a lower rate of return. This seems logical since this is an aerobic process. Returning sludge at a rate that maintains DO in the return sludge tends to maintain aerobic conditions at the head of the aerators where the greatest oxygen demand occurs.

When the Gary plant went into operation in August 1940 a 25 per cent rate of return was used. In about two weeks a good floc had developed and the final effluent was clear and sparkling. In two weeks more the return sludge in the secondary manholes had developed a foul odor. Septicity had developed because the sludge was not being removed fast enough from the secondary clarifiers. Another return sludge pump was put into operation, raising the rate of return to about 33 per cent and the odor disappeared after a few days. That showed that a higher rate of return was required if the return sludge was to be kept fresh. Over the years the Gary plant was operated with return rate that was 33 per cent or higher. It was not until 1951, when the data from the ammonia still waste experiment was analyzed, that the benefits to be derived from a high rate of return were understood. At Gary, with all three return sludge pumps operating, it requires only 2½ min to return sludge from the center of eight secondary manholes to the center of the entrance end of all aerators in service. A research project on the effect of various rates of return at different activated sludge plants could develop further information on this subject.

From the Floor:—I had a little experience in this matter in industry some time ago. In using the returned sludge we could use the same sludge and not dilute the mixed liquor to the same extent as we were doing before. The stimulation of the growth of the microorganisms was more active by using the returned sludge. The microorganisms were reduced and the sludge was better. My point is that we will not always gain much by using return sludge; on the contrary, we may gain something by reducing it sometimes.

Professor Sawyer:—I certainly am in full agreement with everything Bill Mathews has said. I want to say once again that the final clarifier and the facilities for getting the sludge out of the clarifier back into the aeration tanks is part of the process.

Linn H. Enslow, Editor, "Water and Sewage Works," New York, N. Y.:*—There is one item that has not been discussed here, and that is the more return sludge put back into the influent in the process of diluting the sewage, the more you are building up a repository of oxygen. That is to say, the more water you have in the aerators, the greater volume of oxygen you are going to reserve for a given amount of BOD. I have always thought that was a great help. Every time it rains on an activated sludge treatment plant I notice the plants do a lot better.

Chairman Hatfield:—I think we can get along with a lot less volume and still return the same number of pounds of sludge to the aerator at a much lower volume if we have a high concentration of return sludge. I think we need to get away from thinking of per cent by volume and return the sludge like other ingredients—on the basis of pounds of sludge returned. Then, if you want to think in terms

* Deceased November 3, 1957.

of the volume of water you are going to return, you have another factor. Personally, I think it is pounds of sludge that determines the return.

E. Sherman Chase, Partner, Metcalf and Eddy, Consulting Engineers, Boston, Mass.:—There are two factors that have not as yet been mentioned. First is the temperature factor. Activated sludge is a biological process, and organisms work according to the temperature of their environment. The second is a matter of air absorption. Part of the air is derived from absorption from the air surface. Agitation is another factor in the process.

Professor Sawyer:—Dissolved oxygen is certainly a fundamental factor in this whole thing. We have all been running dissolved oxygen determinations on return sludge. There is one thing that has not been mentioned here today, and that is a means of control. I am thinking of the oxidation reduction, which allows you to determine what the conditions are when you have no dissolved oxygen. A few people have been bringing this to our attention; and, as I see it, this is going to be one of the big developments in this field that can be put on a practical operating basis wherein you can control the rate of return sludge and the rate of air applied to the aeration tank. I look forward to a really good control in the activated sludge process.

Mr. Haseltine:—The activated sludge process is complicated, but I think the matter of return sludge can be made quite simple, particularly if you will think of it as the percentage of the mixed liquor flow rather than the sewage flow.

If you have 50 per cent sludge in a sample at the end of a 30-min quiescent period, it means you will have to return sludge at 100 per cent of the sewage flow, or 50 per cent of the mixed liquor flow, or you cannot return the sludge to the aeration system in 30 min.

Mr. Gould:—The more sludge returned, the more solids circulate through the final tanks, and the greater is the problem of their separation and removal. If the sludge in the final tanks can flow down and out quickly, and that can be made to happen in 30 min or so by utilizing sludge density currents, the sludge remains fresh. Unnecessarily high rates of sludge return limits the capacity of both final and aeration tanks.

In Milwaukee they developed a type of mechanism where the flow is vertical. The sludge is not held too long and return rates are moderate. I am a strong advocate for relatively low return sludge rates, and I see no necessity for building them up higher than necessary.

Trickling Filters

Gordon M. Fair, Professor, Harvard University, Cambridge, Mass.:—I have tried to bring together some ideas on loading of trickling filters. Certainly we can identify at least two kinds of loadings which we must take into account in the design and operation of trickling filters: (a) the liquid loading, and (b) the BOD loading.

The liquid load is important in the hydraulic design and operation of trickling filters. It determines the sizing of the distribution system and the collection system. In the past, this load has generally been expressed in million gallons per acre per day or gallons per day per thousand square feet.

I would like to put in a plug for the recommendations of the Federation's Subcommittee on Standardization of Units (THIS JOURNAL, **29**, 2, 134; Feb. 1957). The idea expressed in their report which recognizes the liquid load as a velocity and recommends the units of feet (vertical) per day has much to be said for it. The Subcommittee indicates ranges of 5 to 15 fpd for hydraulic loads (1.5 to 5 mgd/acre or 37,500 to 112,500 gpd/1,000 sq ft) for low-rate filters and 15 to 10 fpd (5

to 35 mgd/acre or 112,500 to 750,000 gpd/1,000 sq ft) for high-rate filters. I think that is a very simple concept. Each unit depth of filter is washed by the same amount of water and, therefore, has the same load impressed upon it.

The liquid loading is easy of conception, measurement and expression. By contrast, the process or BOD loading of trickling filters, although easy of conception, is difficult of measurement and expression. The Subcommittee on Standardization of Units recommends the use of pounds of BOD per day (in the waste applied to the filter) per thousand cubic feet of filter volume. Indicated ranges of BOD are 5 to 25 lb per 1,000 cfd (220 to 1,100 lb/day/acre-ft or 0.14 to 0.68 lb/day/cu yd) for low-rate filters and 25 to 300 lb per 1,000 cfd (1,100 to 13,000 lb/day/acre-ft or 0.68 to 3.2 lb/day/cu yd) for high-rate filters.

The Upper Mississippi River Board of Public Health Engineers and Great Lakes Board of Public Health Engineers have set up an upper BOD limit of 15 lb per 1,000 cfd for low-rate filters and draws the distinction between loadings of filters at high and low latitudes. They take into account the problem of temperature. It is far more important in trickling filters than in the activated sludge process because the trickling filter is exposed to the air temperatures and, therefore, the filter temperature is lowered or raised as the case may be.

Fundamentally, the recommended units for BOD loading are inadequate expressions of the process load on trickling filters because the operation is a rate process in which the load impressed upon a unit volume of the filter varies with the location in depth of that volume. The load is highest in the top layer of contact material and lowest in the bottom layer because part of the load is removed in the intervening layers. Loadings as pounds of BOD daily per thousand cubic feet, acre-feet, or cubic yard presumed to be equal are not actually equal at the top level of the filter and the bottom level.

A supplemental statement of the depth of the filter is helpful, and that was frequently done in the past. Thus a loading of 15 lb/1,000 cu ft in a 4-ft filter or a loading of 15 lb/cu ft in a 10-ft filter were entirely different concepts. Accurate comparisons can be made, therefore, only between filters of equal depth.

Strictly speaking, the size of the contact medium should also be specified because the contact opportunity in small-grained filters is substantially greater than that in large-grained filters. In other words, there is a much larger area of active medium in a small-grained filter than in a large one.

The process loading of trickling filters is simplified in one sense and complicated in another by the various ways in which effluent is recirculated in some filters. The return of effluent makes for more uniform loading relative to depth because the dilution of the influent establishes a smaller differential between the BOD of the applied sewage at the surface and the bottom of the bed. This is something that was not brought out in the discussion of activated sludge. It is also true that as you increase the circulation, as you fundamentally do by increasing the amount of return sludge in the activated sludge process, you get a more even loading of the tank. There are reasons to believe, however, that the treatability of sewage which has made one or more passages through a filter becomes progressively less. Professor Thomas has suggested means for taking this factor into account, and Dr. Imhoff and I have presented in our joint book * a table of values which indicates the average number of effective passes that correspond to different

* Imhoff, K., and Fair, G. M., "Sewage Treatment." Second Edition, John Wiley and Sons, Inc., New York, N. Y. (1956).

hydraulic recirculation factors. A significant observation is that the average number of effective passes rapidly reaches a maximum (2.8 for a 10 per cent decrease in the response to removal during successive passes). That is, one cannot go forward and expect improvement all the time. This places a limit on the attainable improvement in treatment by recirculation. It is probably also true in the activated sludge process that there is a limit on the amount of recirculation that can be held effective. The greater the decrease in treatability, the smaller is the amount of recirculation that will contribute effectively to treatment.

Joseph A. McCarthy, Chief, Lawrence Experiment Station, Massachusetts Department of Public Health, Lawrence, Mass.:—As indicated here, there are considerable variations in the concept of filter loading; thus, it could not be expected that all would agree on how we shall express the loading. I shall devote most of my discussion to a possible approach to the reasons why certain types of sewage, particularly sewages contained in industrial wastes, appear to have very widely marked changes in tolerance. I have not included any consideration of rate. I have simply taken experimental results and determined the maximum amount that could be removed by a trickling filter, regardless of its efficiency, if more and more load is added. Some of my data represent an approach of only 50 per cent; others represent 95 per cent.

At the Lawrence (Mass.) experiment station, the domestic sewage is quite strong. There also is a rather wide variety of single-pass trickling filters, some of which have been operating since 1890. The study was directed to the concept: how much removal can be obtained under any terms provided you keep on increasing the load? We found the factor was about 32 lb/1,000 cu ft of material; that is about 1,400 lb/acre, or about 0.86 lb/cu yd. This is in a single-pass filter. If the optimum recirculation is stepped up, it was found that the removal could be increased only to about 38 lb, 1,000 cu ft. The possible reason is not only the diminishing return that Professor Thomas has shown, but the fact that you are not getting any particular amount of toxicity in ordinary domestic sewage. Therefore, the increase you gain by circulation towards a maximum load is probably at least partly mechanical.

When industrial wastes are considered, you get an extremely variable material. We have been working with tannery wastes which have been coagulated by chemical means or by carbon dioxide. With an optimum removal of the calcium and sulfur and the best possible pH, the loading on a single-pass filter was about 35 lb/1,000 cu ft, almost the same as with the domestic sewage. However, since one of the factors involved in the treatment of tannery waste is toxicity, a loading of 150 lb/1,000 cu ft was obtained with optimum recirculation, which is a considerable difference.

With wool-scouring wastes there is an interfering substance no matter how well it is treated. There are included extremely stable compounds, such as the lanolin family. It was found that the shut-off value was around 11 lb, or about one-third of what can be expected with domestic sewage if uncut wastes are treated. When as much grease and dissolved fats as possible are removed, the loading is only 20 lb/1,000 cu ft. Even with recirculation not more than a 30 lb/1,000 cu ft loading can be obtained.

On the other hand, some of the chemical wastes produce astonishing results. One waste was high in nitrogen and a loading of 50 lb/1,000 cu ft on the trickling filter was possible. With optimum recirculation, the loading got up to 155 lb/1,000 cu ft. There are a lot more data, but the loadings go up and go down, depending

pretty much on how inhibitory the substances are in the wastes. Pine oils in wastes (high in sodium sulfate) give maximum loadings of only about 12 lb, probably due to the influence of sulfate with formaldehyde.

At Mansfield, with a single-pass filter, only about one-half the sewage load was obtained. Increasing the recirculation rate beyond the optimum yield, up to 10 times, resulted in a loading up to 30 lb; if the rate was increased 20 times, it was possible to get up to about the same maximum loading as was done on sewage.

These loadings are not intended to be significant in themselves. They are probably not particularly good guides, even in waste treatment, but they are significant in that no matter where we go now industrial wastes, especially in intermittent quantities, are going to be part of the problem of the trickling filter plant operator.

Mr. Haseltine:—Mr. McCarthy's discussion was very interesting to me. I have the feeling that while we normally talk about a volumetric recirculation ratio, we should also consider the recirculation of BOD. In a municipal sewage treatment plant, the recycled BOD is relatively low and so of little significance, but in industrial wastes, with a much stronger concentration of BOD, you may get a big build-up in recycled BOD, which tends to reduce the efficiency of the filter.

Professor Sawyer:—I certainly was interested to hear Mr. McCarthy mention the importance of the nature of the substrate with which you are dealing. It is a matter of biological assimilability. You might say, it is how well the organisms love the food or how many points of attack the food material has.

J. Henry L. Giles, Deputy Director, Public Works Department, Hartford, Conn.:—I do not know to what extent the standard-rate filter is being built today; that is, the low-rate filters. Most of those that I have seen are high-rate filters. For those who have the low-rate filters, we have had some rather interesting experiences in Connecticut, primarily at state institutions where we have strong laundry wastes. The flow variations were excessive; they range in ratio from 1 to 10, more or less, between the low-flow rate at night and the peak flows when the laundry wastes were being received. In other words, to maintain the maximum efficiency of these filters it was necessary to install a recirculation pump to keep the filter moist. Even with mechanical distributors, there just was not enough water during low flows to maintain the best growth on the stone. Much higher BOD removal was noted during the 4-hr peak flow periods than when the filters tended to dry out. By maintaining high rates of recirculation at times of low flow a green condition was maintained over the stone and the over-all BOD and solids removals were far in excess of what had been obtained without recirculation.

Mr. Enslow:—We were talking about frequency of application to the trickling filter, or dilution. Was there some consideration given in the standards to whether or not the filter is of the old siphon application or of the more continuous application?

Professor Fair:—There is no differentiation in the actual loading value, and I do not see how it could be made except by adding the recirculation factor to the loading. Undoubtedly, what the recirculation does is to iron out the loading on the filters, making the loading more significant. It has made the present method of expression of loading a more significant factor than it has been in the past.

George A. Prince, Chief, Public Health Engineering Section, Colorado State Dept. of Public Health, Denver, Colo.:—Pertaining to hydraulic loadings, I am wondering if there is any magic to the gallons per acre per day rate, *i.e.* the 4-mgd/acre and 10-mgd/

acre rates? Is there an intermediate rate that would be suitable; and if not, why not?

Mr. McCarthy:—We have had some experience with intermediate rates. Purely on hydraulic loading we have found, everything else being equal, that at rates of 4 or 5 mgd/acre you get a rather steady drop in efficiency. Apparently, at times you can find a minimum efficiency spot somewhere between 8 and 12 mgd/acre, whatever it happens to be for that particular substrate. After that you get better efficiency. As far as magic goes, I do not think there is anything sacred about the rates.

Professor Fair:—A very important factor in the design of trickling filters is to understand that a trickling filter is not merely a hydraulic mechanism; it is a pneumatic mechanism. It must pass air downward or upward through the filter. If a filter has been built to a certain rate of application and then shifted to a higher rate, unless the underdrainage system is modified at the same time so there is an adequate passage of air through the filter, trouble will ensue. This is clearly demonstrated at Stuttgart, Germany, where a great deal of experimentation of trickling filters was carried on in which the heavy loadings resulted in overloading of the underdrains. The whole filters went septic, as one would expect.

Jack E. McKee, Professor of Sanitary Engineering, California Institute of Technology, Pasadena, Calif.:—I would like Professor Fair or Mr. McCarthy to say a few words about the nitrogen in relation to trickling filter operation.

Mr. McCarthy:—Many times we have studied the nitrogen cycle to find out what happens, what form the nitrogen gets into, and what form it goes out as. I think it is a function of two things: one is the development of the filter, and the other is the hydraulic rate of passage. One of the reasons I think intermediate-range filters and even some very high-rate filters do not do any good is the fact that the nitrogen does not know what to do with itself. In the intermediate range, apparently, it goes rapidly back and forth from oxidized to reduced. It upsets everything. While there is nitrogen present, the waste does not seem to be available in the proper proportions to the BOD loading. Probably there are not any good answers.

Mr. Giles:—One of the things which has not been mentioned, which I think is extremely important, is the size of filter stone. The general experience we have had in Connecticut is that the 2-in. or even 1½-in. stone gives a much better effluent at extremely high rates of dosage.

Charles Saunders, Superintendent-Engineer, Linden-Roselle Sewerage Authority, Linden, N. J.:—I would like to comment on this effective stone size. At the sewage treatment plants serving the New York Thruway service centers there are about three flow peaks per day and for about 2 hr during the rest of the day, there is practically no flow. We have found that at the treatment plants where the stone size is between 3 and 4 in. there is no trouble with filter ponding, etc. At the plants where the smaller-sized stone is used, we are having continuous trouble.

From the Floor:—I believe that the loading per cubic volume is not significant. In other words, loading per square foot up to certain limits does not vary the per cent reduction of BOD.

Professor Fair:—I would be satisfied with loading per acre or per square foot in a filter of such and such depth. That would be as informative as anything you could have rather than loading per cubic foot or yard or per thousand cubic feet.

I would like to ask a question of the group. It is whether anyone has had any experience with the step loading

of trickling filters; it is something that looks promising on the surface and is actually analogous, of course, to the step loading of activated sludge units. Personally, I do not call it step loading, I call it load distribution; but it acts the same way whatever it may be called.

Mr. Enslow:—What do you mean? How do you apply step loading?

Professor Fair:—This was a new idea which was propounded in the proceedings of the American Society of Civil Engineers * by Professor Ingram of New York University in which sewage is brought in at various levels of the filter in the same way sewage was brought in at various points along the aeration tanks in the activated sludge unit. I believe there is at least one place where a 10-ft filter or a 30-ft filter has been used.

From the Floor:—I had reason just last week to go over some of Professor Ingram's data at his request, and I happen to remember some of the values, although I do not have them exactly. In his pilot-plant work he was working with an 18-ft filter, broken down into six sections of 3-ft depth each. There is an air interchange in each section. The first step was loaded with a certain quantity of raw material. The effluent that dropped directly from that step was loaded with a second step of raw material to build it up to about the average loading, or maybe a little bit above the average loading, and applied as the second step. The third was loaded with more raw material to bring it up to an average loading.

Professor Ingram found that in the 9 ft of depth he could get efficiencies way up. With the additional food loading beyond the 9 ft, however, he found he had to get into the nitrification stage, where he was not putting any more feed in.

In analyzing the data for the entire 18 ft of depth, the loading ran something like 5,000 to 6,000 lb/acre-ft. On that basis there was an 80 per cent BOD reduction through the filter alone, without use of a clarifier. In analyzing the first 12 ft of depth, the loading went up to something in the range of 10,000 lb/acre-ft, with about a 73 per cent reduction of BOD, not including clarification. That is step feeding.

I think you will find it very enlightening. We are waiting to see what the data are going to be for larger installations where I think we will get some real results. (*Editor's Note*—Dr. Ingram was not in attendance at the meeting.)

Stabilization Ponds

Professor H. B. Gotaas, Dean of Engineering, Northwestern University, Evanston, Ill.:—For the last few years while we have been working on these oxidation ponds we have continually tried to use the name stabilization pond, which we believe to be the best name.

I shall briefly go over the factors that affect the operation of a stabilization pond of an aerobic type. There are stabilization ponds of anaerobic character; that is, if you empty large amounts of sewage (organic matter) into a pond and let it decompose anaerobically you would get stabilization. You would also have nuisance problems. I will limit my comments to the type of stabilization pond which can be maintained aerobically, at least most of the time.

Aerobic stabilization ponds can obtain their oxygen from two main sources: (a) atmospheric reaeration and (b) photosynthesis. Atmospheric reaeration will usually provide not more than 10 to 20 lb of oxygen per acre per day, whereas photosynthetic oxygen may provide 250 lb per day/acre under proper light conditions. Hence, the most effective operation of

* Ingram, W. T., "A New Approach to Trickling Filter Design." *Proc. Amer. Soc. Civil Engrs., San. Eng. Div.*, **82**, SA3, 999 (June 1956).

the stabilization pond can be obtained when there is a maximum photosynthesis or a maximum algae concentration to provide the oxygen.

There are certain variable factors in ponds that cannot be controlled: (a) the amount of visible light; (b) the temperature; and (c) the wind factors. The controllable factors in the operation and design of a stabilization pond are: (a) loading, in pounds per acre per day; (b) depth; (c) detention period; (d) recirculation; (e) load distribution; and (f) pond operation, either in series or parallel. Some of these variables are interdependent. For example, the loading is related to the strength of the waste as well as to the depth and detention period of the pond. Algae concentration is related to the amount of sunlight and the amount of nutrients. Since the quantity of nutrients is dependent on the loading, the algae concentration is also affected by depth and detention period.

The depth and detention period can be varied to meet the conditions of sewage, strength, and available light for photosynthesis. The depth-detention period ratio (d/D, d in feet and D in days) may have to be down as low as 1 to 2 in the winter when the pond has no ice cover, and may be as high as 5 to 6 in the summer. Shallow depths will give a higher algae concentration; but in using shallow depths, the algae concentration must be high enough to prevent light penetration to the bottom of the pond. Otherwise, there will be undesirable weed growths. If a high enough algae concentration can be maintained to prevent light concentration at the pond bottom, then there will not be much bother with weeds. I would like to emphasize that oxygen production is a function of the algae concentration and the amount of light.

Another operating factor is recirculation. It is important in the operation of a pond to add oxygen and algal seed at the influent end of the pond. Otherwise, a septic anaerobic condition will develop at the entrance of the pond. Recirculation from 0.2 to 1½ pond volumes times, depending on the strength of the sewage, is desirable.

Load distribution is very similar in a stabilization pond to the load distribution in activated sludge or in trickling filters. In the stabilization pond, if all of the sewage is introduced in one place, there develops flocculation and settling of solids and, in turn, local anaerobic conditions due to the accumulated sludge on the pond bottom. It is my feeling that the most efficient operation will obtain when the incoming sewage, with the recirculation added, is distributed over the first half to two-thirds of the pond. In other words, let the flocculated solids settle to the bottom. There will be a thin layer over the first two-thirds of the pond. That is practically the same as loading an activated sludge process at intervals along the aeration tank.

Temperature affects the rate of bacterial activity and the rate of algae growth. In the case of most of the common green algae that grow in the ponds, an optimum growth temperature is from 20° to 25°C.

The temperature of the water can be partially controlled by varying the depth of the pond and the detention period. If the water temperature gets too high, metabolism of the algae will be reduced, and the growth of the algae will be reduced. Likewise, in the wintertime, if the pond freezes over, the algae production will be lowered, and the amount of oxygen produced will be very small.

The next factor for consideration is series ponds versus parallel ponds. There is a great disadvantage to operating ponds in series unless the first pond is operated as a septic anaerobic pond. If this is done, then a good deal of the BOD material can be taken out in the first pond and the second pond can be used as an aerobic pond to stabilize the remaining BOD and turn

out an effluent with considerable dissolved oxygen. However, if it is desired to maintain aerobic conditions throughout, it is a disadvantage to operate ponds in series.

There is the problem of predatory zooplankton in the stabilization ponds. These predators are organisms such as rotifers, cyclops, cladacera, etc. They will eat the algae, and I have seen a few ponds in which the algae concentration is reduced with detrimental effects. The ponds operate on a less efficient basis when the algae are eaten up by the zooplankton which develop with long detention periods. Too long detention periods and too shallow depths also provide conditions leading to the development of high pH. The algae will reduce the alkalinity in the water by taking carbon dioxide from the bicarbonates, thus raising the pH. Bacteriological oxidation is inhibited at pH values above 9.5 which readily occur when excessive light produces large algal growth.

Finally I want to emphasize that to produce oxygen photosynthetically, light is a very important factor; and the depth-detention period ratio between winter and summer (except near the equator) will have to vary widely.

W. W. Towne, Sanitary Engineer, Robert A. Taft Sanitary Engineering Center, USPHS, Cincinnati, Ohio.:— I think Professor Gotaas has covered very well the factors requiring consideration in the design of sewage stabilization ponds. The Public Health Service has been involved in studies of raw sewage stabilization ponds since 1950. Studies and observations were made on some of the first raw sewage ponds in North Dakota. These studies have been carried on within the limits of resources, and the results of an experiment at Kearney, Nebr., have been reported (THIS JOURNAL, **29**, 4, 377; Apr. 1957). During 1955 and 1956 the Public Health Service and the state of North Dakota joined in a cooperative study of ponds in those two states and some of this work was reported at the Los Angeles Meeting. The study is now complete, and the report is available.

Studies are continuing on what I would call large-scale pilot-plant installations at two locations, Fayette, Mo., and Lebanon, Ohio. The Missouri studies were started almost a year ago. I would like to emphasize that the work of the Public Health Service has been confined to studies of full-scale installations treating raw sewage. The primary purpose of these installations is to provide a low-cost, adequate and simple method of sewage treatment. In connection with cost, parenthetically, I might say that in the Dakotas the costs range from around $4.50 per capita to about $38 per capita.

Briefly, our findings based on the Dakota studies and observations may be summarized as follows—properly designed and operated stabilization ponds are providing a degree of purification comparable to that obtained by conventional treatment processes. Like other treatment devices they have advantages and disadvantages and should not be considered a panacea for all sewage treatment needs. However, they may be used with a reasonable degree of success under appropriate conditions.

I do not think all of the answers have been obtained by any means. The Public Health Service has worked closely with the University of Texas and the University of California, where the theoretical basic studies have been carried on. We are trying to apply the theories to field operation. As Professor Gotaas pointed out, it has been found that while a depth of 2 ft might be the most efficient depth from the standpoint of the oxygen production, it may be necessary to use a greater depth to preclude aquatic vegetation growth at the bottom of the pond.

In those areas where mosquito propagation is a particular problem and a potential health danger, as well as a

nuisance problem, we have found that pond depths ranging from 3 to 3½ ft are quite effective in keeping weed growth to a minimum. In observations on mosquito propagation, it was generally found that the mosquito growth is confined to those ponds that have protected areas where there is emergent vegetation along the shoreline or in the pond. There have been some recent reports of mosquito infestation in ponds having no apparent protective areas caused by vegetation. This is an operational problem that may be particularly important in the southern states.

I would like to point out from a practical standpoint what we think should be some of the future areas of study on sewage stabilization ponds. More specific loading limits are needed for different climates. The work at California has given limits for maximum efficiency. In designing a treatment unit for application in the states in which they are being used extensively, we are willing to sacrifice some efficiency in area for simplicity in operation and maintenance. Therefore, I think what is needed is not so much the maximum amount of oxygen that can be produced, but the maximum loading that can be placed in a pond and still maintain aerobic conditions under minimum light values for that particular area.

More information is also needed on the practical optimum operating depth. Reports received to date on this subject are rather conflicting. A study is needed on the methods of achieving efficiency of depth in an area at different seasons. Other areas of study include methods to obtain a low algae effluent. There are cases where it is desirable to reduce the algae in the pond effluent. Another area is the economic and feasible means of sealing pond bottoms. Unsatisfactory bottom conditions have precluded the use of stabilization ponds in some areas. There is always a need to study methods of inhibiting excessive evaporation, and to give further consideration to odor control during critical seasons. During certain critical seasons, there may be one or two weeks in which anaerobic septic conditions are approached. All the other seasons of the year will support an aerobic environment. In the Kansas City area, successful odor control in ponds has been achieved by the addition of nitrate during the short critical periods. And then further study is needed to improve methods of insect control that will be compatible with the operation of algae-laden ponds.

E. R. Hermann, Industrial Hygiene Engineer, Medical Division, Humble Oil & Refining Company, Baytown, Tex.:—I have done about three years of research on waste stabilization ponds, including experimental work in the laboratory, field work on pilot plants, and a statistical analysis of data collected on some 188 ponds in communities in Texas. Waste stabilization ponds run the whole gamut of biological commensal systems, at least of the algal-bacterial types. There are some waste stabilization ponds that operate heavily on the algal side in which algae, through photosynthesis, provide nearly all of the oxygen for satisfying the biochemical oxygen demand. BOD is stored in such a system as algal cell material and must be removed to avoid future exertion of the BOD at an inopportune time or place. At the other extreme, there are ponds in which nearly all of the oxidative processes are accomplished by bacteria, a large proportion of the required oxygen being provided from chemically combined sources as in anaerobic digestion. In the latter type of pond the supply of light energy is not too important.

While pond area is the proper criterion for the design of stabilization ponds with a lot of algae, temperature is most important in the design of stabilization ponds operating largely

in the bacterial phase. Algae in this system, however, are important in that they use up the liberated carbon dioxide to avoid septic conditions. Septicity and anaerobic digestion are not synonymous.

As I indicated yesterday on the research symposium, a particular type of pond operating on an aerobic-anaerobic daily cycle can be designed with temperature as the major controlling factor. As a result we may accomplish all of the sewage treatment processes customarily provided by complete treatment plants of the trickling filter or activated sludge type, including primary sedimentation and sludge digestion, all in one continuous process using the simplest of reaction vessels—ponds. Such waste stabilization devices can be designed and constructed for about one-third the cost of present complete treatment plants and operated at about one-half the cost.

I think this type of treatment deserves a lot more attention than it has gotten in the past, especially for small installations in warm climates.

Professor McKee:—Professor Gotaas has indicated he does not favor ponds in series and that when the detention period is long, too much carbon dioxide will build up and the number of algae will decrease. Mr. Towne has indicated that some of the problems with oxidation ponds are concerned with algae and air. Putting all these things together, I would like to ask what consideration has been given to ponds in series, letting the zooplankton build up in the last pond and with fish in the pond to feed on the zooplankton.

Mr. Towne:—This is a possibility, of course. Some work has been done in Scandinavia on ponds in series where they did just that.

Professor McKee:—The Germans do it rather extensively.

Mr. Towne:—Very extensively. I would like to mention one point concerning multiple inlets and the even distribution of the sewage. We have found that the wind is a good distributor. With a single inlet, the wind keeps the solids well distributed throughout the pond, and with raw sewage the wind has an important effect. Under quiescent conditions, the hydraulic distribution is much more important than it is in the areas where we get a good mixing and complete distribution by wind action. When we sampled 50 or 75 ft away from the inlet, the chemical, biological, and physical results were essentially the same as in the far corner of the pond. There was complete diffusion by wind action.

Professor Gotaas:—With regard to the ponds in series, there is nothing wrong with putting ponds in series; it is a matter of economic use of the land. If you want more area and more pond volume, then ponds in series can be fine; but you do not get the most efficient use. If you are going to decide on the basis of area and volume, then you will get greatest aerobic oxidation of the waste in the parallel ponds.

Mr. Enslow:—I am interested in the effect of the algae on the pH. I would like to know what happens and what is done with it after it happens.

Professor Gotaas:—In the pond operating under good light conditions, for instance, in the summertime, and a high algae concentration, it is not uncommon to raise the pH up to 10.5. I have seen the pH go up to as high as 11. The algae adjust themselves to that pH; bacteria do not. So what happens if you allow the algae to get the pH too high is that the bacterial decomposition of organic matter is inhibited but the algae will go on growing as long as food is available.

John W. Wakefield, Chief, Sewage and Industrial Wastes Section, Florida State Board of Health, Jacksonville, Fla.:—In Florida we are concerned about insect production. We are not only concerned with mosquito production, but we also have an insect called the blind mosquito. They are midges.

They grow in the bottom of some of the lakes which are receiving treated sewage, not raw sewage. Apparently the nutrients from sanitary wastes are being charged with the responsibility for these midges. I want to know if anyone has had any experience with this in oxidation ponds.

Professor Sawyer:—I am not sure what the midge is that Mr. Wakefield is talking about. If it is the May fly or some similar one, they, of course, derive from the larvae which live in the bottom sediment. So I presume in this case he is dealing with these bottom organisms which hatch periodically and go into the flying stage and cause trouble. It is not only in smaller ponds where you have this trouble, but you have it along the Mississippi River.

Sol Pincus, Consulting Engineer, New York, N. Y.:—We had an experience with midges during the World Fair in 1939. There was a period at one time when it seemed as though the fair would not get underway because of the enormous production of midges due to the creation of two ponds in the fair grounds and the fertilization of the area with nitrates at the same time. It got very bad. We managed to control them, primarily through the use of arsenic compounds. It was quite an expensive operation. I was wondering about the use of larvicides for the midge or for the mosquito, and also whether chemical weed killers could be used without interfering with algae production in the stabilization ponds.

Theodore Jaffe, Professor of Civil Engineering, Alabama Polytechnic Institute,, Auburn, Ala.:—I have heard two different views expressed here on the effect of sunlight and pond temperature on stabilization. Is sunlight of any consequence or not?

Professor Gotaas:—There is nothing wrong with operating a pond in the purely bacterial phase. In that case, the temperature is the major factor; but where is your oxygen coming from? You can get up to 10 or 15 ppm of dissolved oxygen per acre per day by aeration from the atmosphere, depending upon the initial oxygen saturation of the water. If you load any more than that, then you are either going to have anaerobic conditions and the stabilization has to take place anaerobically, or else you have to get oxygen from somewhere else. If you get oxygen photosynthetically, then light is the important factor, plus the photosynthetic efficiency of the algae. It boils down to this. It is possible to have a pond that is right on the borderline where considerable anaerobic decomposition is taking place in the bottom, and where there are enough algae growing on top to produce enough oxygen so that the odors are inhibited. When you operate a pond on that basis and get cloudy weather and variations in the loading, you are flirting with anaerobic odorous conditions. To me it is just a basic principle that if you are going to have aerobic conditions, you have to have oxygen some place. With photosynthesis you must consider the light. In the case of two ponds in Norway, they are aerating ponds. They overcome the oxygen problem by mechanical aeration.

Dr. Hermann:—In fundamental principles I believe Dr. Gotaas and I are in agreement; however, it should be clear by now that in application we are talking about two different types of algal-bacterial commensal systems. Dr. Gotaas has discussed and apparently advocates the use of an algae culture as a sewage treatment device in which photosynthetic oxygenation supplies most of the oxygen for satisfying BOD, and from which algal cell material may be recovered for use as feed or fuel. I, on the other hand, am talking about a diurnally cycling aerobic-anaerobic pond in which moderately aerobic conditions are attained during the daytime and alkaline anaerobic (not septic) conditions take over at night. Thus the processes of

primary sedimentation, aerobic liquid waste stabilization, and anaerobic sludge digestion are combined into one system. Although algae are not present in large numbers in a system such as this and are not used to concentrate waste substances through protoplasmic synthesis, they play an important role in providing dissolved oxygen, maintaining the pH on the alkaline side, and keeping the ORP at a desirable level. As in the biological systems of trickling filters and sludge digesters, chemically combined oxygen is transferred to satisfy a lot of the BOD.

I feel reasonably sure that Dr. Gotaas' algae ponds and my algal-bacterial stabilization ponds will both find growing acceptance as means of treating waste waters. Relative popularity of the two methods will depend upon economic considerations. For a given community with its own particular problems, will it be better to harvest and market algal cell substances to offset sewage treatment costs or will it be cheaper to limit the growth of organic solids and eliminate the problems of algae separation and drying at the expense of mineralizing the plant effluent? The practicing engineers will have to supply the answer.

Ralph C. Sweeney, Sanitary Engineer, New York State Health Department, White Plains, N. Y.:—This type of treatment was just mentioned for Norway. This indicates its application in northern climates. When you think of northern climates in the wintertime, you immediately think of ice; and no one has made any reference to that.

Professor Gotaas:—Stabilization ponds do not operate satisfactorily when covered with ice. There is very little photosynthesis or atmospheric aeration. Fortunately, bacteriological decomposition is also inhibited by the low temperature. Under conditions of ice cover the sewage solids settle to the bottom to be decomposed when temperatures rise. This places an excessive load on the pond in the spring.

Mr. Towne:—The ponds in the Dakotas have stayed aerobic depending on the nature and thickness of the ice, up to 4 to 8 in. When the ice gets thicker, the ponds do go anaerobic. The critical period is during the transition from ice cover to open water when they go from anaerobic to aerobic conditions. In the Dakotas low loading levels have been maintained to reduce the period of transition to a minimum. From experience it has been found that if the BOD load is kept to 15 to 40 lb per acre, there is a minimum period of transition in going from anaerobic to aerobic conditions. There is, therefore, a minimum production of odor. I think the question was asked whether you can use weed killers and insecticides without affecting the algae. I would prefer that a biologist speak on that point.

Chairman Hatfield:—It would depend on the material and whether the particular weed killer was toxic to algae. You would have to test the particular weed killer.

From the Floor:—We are planning to conduct some experiments on the toxicity of various insecticides and weed killers to algae. As far as I know, our biologists feel that DDT will not seriously affect the population.

Donald C. Kalda, Chief, Water Pollution Control Section, South Dakota Department of Health, Pierre, S. D.:—I might comment concerning a court case we went through a year ago. It so happened that the only available area was less than 500 ft from a residence and close to the highway. The property owner brought suit. It was decided the city had every right to place the pond on this site on the basis of the technical data presented on the operation of stabilization ponds.

There are some reasons, however, why we would like to get these ponds a reasonable distance from the city. Some people have the idea that they are undesirable and create a nuisance condition. In South Dakota, of course,

we are quite enthusiastic about the construction of these facilities, probably because we have so many small towns. These ponds have made sewers and sewage treatment possible in many of the towns which could not otherwise have afforded them.

We have had several installations treating milk and meat wastes in operation for several years, and they have proven quite satisfactory. We keep the BOD loadings down to 15 to 20 lb per day/acre.

Mr. Enslow:—Has there been any objection to the green color the effluent gives to a stream?

Professor Gotaas:—The effluent is green in those ponds that I know of in California where they had considerable algae growth. I do not know of any objection. By the time the effluent is dispersed in the stream, the dilution is usually such that the higher concentration of algae is not particularly noticeable.

If you are emptying these algae into a stream, some nutrients will be present and the algae will continue to grow. This does not seem to create an adverse condition and the algae do not produce a serious problem by continuing to live, in fact they will add oxygen to the stream. However, if they are detained for a long period under very adverse conditions, they will eventually die and reintroduce an oxygen demand. We carried on some experiments over a period of months where we kept the algae from the oxidation pond and had a high concentration under very adverse conditions and found we had no problem with the algae dying off and creating a nuisance.

TIPS AND QUIPS

Special Drop-Shafts

Vertical drop-shafts to interceptors located 80 to 100 ft below the ground surface have received special study in connection with the design and construction of the interceptor system to serve the Allegheny County Sanitary Authority (Pittsburgh, Pa.). The interceptor will flow under pressure; accordingly, model studies were made of the gravity flow in a vertical pipe line, horizontal flow of air and water under pressure, and the upward flow of air opposed to the downward flow of water in vertical pipe lines.

As a result of the studies, the vertical drop-shafts are being designed so that the sewage flows down in a spiral path. Shaft sizes vary from 8 to 36 in. and the maximum flow in any shaft is 46 mgd. Certain drop-shafts serve as air vents and also separate air vents are provided to permit the escape of air drawn into the sewage through flow in the drop-shafts.

Accidental Death Decrease

Accidents took an estimated total of about 94,000 lives in the United States during 1957, or somewhat fewer than in 1956. It was the first time in three years that the number of fatally injured showed a reduction. Accidents arising out of and in the course of employment were responsible for about 14,500 deaths in 1957. Continuous attention to safety will avoid the addition of sewage treatment plant accidents to the above statistics.

Everyone has his good days and bad days. Many suggestions have been made on how to "climb out of the dumps." Public opinion polls report that, as a tonic for the blues the average person turns to entertainment, religion, or to occupational therapy, otherwise known as just plain hard work.

Pesticide Problems

Since in present day complex living the solution to one problem frequently leads to another, the alert operator should be aware of some precautionary measures about the use of pesticides and related chemicals.

Animals and fish may be killed by contact with certain insecticides. They may also die as a result of eating other insects, fish, or animals that have been poisoned. As an example, control operations against malaria mosquitoes on the island of Cyprus were successful, but they also destroyed most or all other species of aquatic invertebrates and all native fresh-water fish. Many instances of the inadvertent killing of fish and other wildlife continually become known.

As a general rule, methoxychlor, TDE, BHC (containing 12 to 14 per cent gamma isomer), and malathion, are less harmful to birds and mammals than is DDT. Toxaphene and Chlordane are similar to DDT in effect. More lethal than DDT are lindane, heptachlor, aldrin, endrin, dieldrin, demeton, EPN, parathion, methyl parathion, TEPP, diazinon, guthion, phosdrin, and thimet.

The order of susceptibility is somewhat different for fish. In general, TDE, BHC, methyl parathion, and TEPP are safer than DDT. Chlordane, methoxychlor, and DDT have approximately the same toxicity. Fish are more severely affected by endrin, dieldrin, toxaphene, lindane, aldrin, and malathion than by DDT. The effect of parathion depends on several factors; it is sometimes less and sometimes more toxic than DDT.

Little or no information is available on the hazards to wildlife and fish of most other new insecticides.

Considerable detailed information, as well as recommendations for the safe use of the various pesticides and other related chemicals, are contained in "Pesticides and Wildlife," by L. F. Stickel and P. F. Springer, Wildlife Leaflet 392, Fish and Wildlife Service, U. S. Department of the Interior, Washington 25, D. C.

Sewer Leakage Tests

Information from 38 cities and sanitary districts in the Pacific Northwest, where infiltration and exfiltration tests have been conducted, reveals a tremendous inflow into existing and old sewers. Roughly one-third of the infiltration tests exceeded allowable limits by as much as 50 times. Exfiltration tests in one city exceeded these limits by as much as 100 times. Allowable limits were obtained from a general rule of thumb that the infiltration in gph per 100 ft of sewer should lie between 50 and 100 per cent of the diameter of the pipe.

Electrophotometer

Modern laboratory techniques make the electrophotometer a desirable and handy piece of apparatus for the well-equipped laboratory. An electrophotometer, and accessories, enables the chemist to perform titrations using colorimetric endpoints with a greater degree of accuracy than would be possible with the unaided eye.

Flexible Porcupine

The wire porcupine, used by many sewer departments as a finishing tool, has been used successfully for cleaning sewers fast where light deposits of sand and silt have occurred. In using the porcupine for this purpose, it is turned on a string of rods and worked with the flow. A head of water builds up and jets through the bristles, washing the deposits down the line as they are churned up by the tool. Working against the flow is advised for grease removal, so the cuttings work toward the operator instead of packing ahead of the tool.

News and Notes

Of Persons and Activities in the Field of Hydrowastes

Dr. F. W. Mohlman has retired as of April 1 from his duties as Director of Laboratories of the Metropolitan Sanitary District of Greater Chicago. Dr. Mohlman served as Editor of the JOURNAL from its beginning in 1928 (through 1943) and has since been Advisory Editor.

Dr. Emanuel Hurwitz has been made Director of Laboratories of the Metropolitan Sanitary District of Greater Chicago. He has been associated with the sanitary district since 1921.

Frank L. Flood, partner of Metcalf and Eddy, died recently. He was well-known in the sanitary engineering field through his many activities and affiliations.

The National Clay Pipe Manufacturers Association has announced the appointment of **Albert J. Reed** as Vice-President-Director of Research. He formerly was Director of Research of the same organization.

Lewis S. Finch, Vice-President and Chief Engineer of the Indianapolis Water Company, was recently elected President of the American Water Works Association. He is a past Director of the Federation.

Dr. Raymond W. Hess has recently been appointed as Consultant-Executive to the Hamburg, N. Y., Water Board. He retired at the end of February from his post as Coordinator of Pollution Research for National Aniline Division, Allied Chemical and Dye Corporation, after nearly 40 years of service. Dr. Hess is Chairman of the Federation Industrial Wastes Committee.

Cornelius S. Gooch has been appointed a service engineer for the Dallas, Texas, office of B-I-F Industries, Inc.

Professor I. W. Santry, Jr., of Southern Methodist University, has recently accepted the Chairmanship of the Sanitary Engineering Division Committee on Publications of the American Society of Civil Engineers. His appointment fills the vacancy created by the resignation of **Dr. Ross McKinney** of M.I.T.

The Chicago Bridge and Iron Company has opened an office in Kansas City, Mo. **Theodore F. Cocks** is the Sales Manager.

Among those recently made Honorary Members of the American Water Works Association were Federation members **Morrison B. Cunningham,** Director of Public Works, Oklahoma City, Okla.; **Victor M. Ehlers,** Director, Division of Sanitary Engineering, Texas State Department of Health; and **Louis F. Warrick,** Chief, Technical Services Branch, U. S. Public Health Service, Washington, D. C. These men have long been prominent in the sewage and industrial wastes field. Mr. Ehlers was made an Honorary Member of the Federation in 1957.

Edward S. Hopkins has moved his consulting engineering office to 410 Professional Building, 330 N. Charles St., Baltimore 1, Md.

Serving as Sanitary Engineer Consultant with the World Health Organization for the current half-year is **Professor Earnest Boyce** of the University of Michigan. In this assignment he will travel to Australia, New Zealand, and a number of South Pacific islands.

Leo Weaver has been appointed to the headquarters staff of the American Public Works Association to assume the duties of Director of Research.

Robert H. Harmeson was recently appointed head of the Peoria Research Laboratory of the Illinois State Water Survey. He succeeds **Dr Max Suter,** named principal engineer on special assignment to study ground-water conditions in northeastern Illinois.

Alan F. Nagle has been named Manager of Keasbey and Mattison Company's Tubular Products and Sewer Pipe Sales Department.

James E. Kurtz has been appointed advertising manager of Pacific Flush Tank Company, Chicago, Ill.

Spaulding A. Norris has been named General Sales Manager of Yeomans Brothers Co., Melrose Park, Ill.

Thomas P. Gallagher of Lynn, Mass., is a recent appointment to the President's Federal Water Pollution Control Advisory Board. He is a sales engineer and distributor of water and sewage works equipment and a member of the New England Interstate Water Pollution Control Commission.

Mueller Company, Decatur, Ill., has announced the appointment of **Dan R. Gannon** as General Sales Manager.

Editorial

THE UNITS OF EXPRESSION FINAL REPORT

The following pages include the final report of the Units of Expression Subcommittee of the Federation Committee on Sewage and Industrial Wastes Practice. The previous report was published in THIS JOURNAL (**29**, 2, 134, Feb. 1957) as a tentative report.

This report culminates 14 years of work by the Subcommittee headed by Dr. Harold E. Orford as Chairman. The Subcommittee was originally organized under the Chairmanship of Dr. Willem J. Rudolfs who retired in 1953. Dr. Morris M. Cohn is Chairman of the Sewage and Industrial Wastes Practice Committee.

As the printing of the tentative report in THIS JOURNAL was a departure from past practice, the printing of this report here as the Federation's Sixth Manual of Practice is likewise a precedent. Its publication is made in accordance with the authority delegated by the Board of Control at its October 6, 1957 meeting. At that time the Board gave publication authority to the Federation Committees charged with the review of manuals before publication. These committees include the Executive, the Program and Publications, and the Sewage and Industrial Wastes Practice Committees.

By the publication of this Manual, the full Federation membership will be informed of the results of this activity and all will have the "Units of Expression for Wastes and Wastes Treatment" for reference. Additional copies may be purchased from the Federation office. Many will probably want to obtain separate copies for their individual requirements.

Perhaps never in Federation history has a subject been discussed by so many. Since the February 1957 printing of the tentative report many Federation members have studied the report and have offered constructive criticism which the Subcommittee used in formulating this final document. Many will be disappointed that the previous recommendation of measuring waste volumes in cubic feet was abandoned. The potential simplification seemed great, but in the light of the practical difficulties of this conversion such an effort seemed futile unless parallel adoption would be approved by other related organizations such as the American Water Works Association, the American Society of Civil Engineers, the American Public Health Association, and the American Society for Testing Materials. In the report, the Subcommittee recommended that the Federation attempt to bring about the use of the cubic foot unit in collaboration with other organizations.

The Subcommittee further recommends that any units of expression not in this list conform wherever possible with the units of length, area, volume, and time used in these Units of Expression. Still another recommendation of great importance is that reports, papers, and manuscripts be prepared with the new units so as to assist in the over-all standardization effort.

All those in the activities of the sewage and industrial wastes field owe thanks to the membership of the Subcommittee that produced this report. Thanks also are due the committees and numerous individuals who offered their helpful comments on the previous drafts of the report.

Units of Expression for Wastes and Waste Treatment

MANUAL OF PRACTICE NO. 6

Prepared Under Direction

of the

FSIWA Committee on Sewage and Industrial Wastes Practice

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By the

Subcommittee on Units of Expression

Harold E. Orford, *Chairman*

Authorized for publication by the Board of Control
Federation of Sewage and Industrial Wastes Associations
October 6, 1957

Ralph E. Fuhrman, *Executive Secretary*

Covered copies of this Manual are available at 25¢ to members; 50¢ to non-members.

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Washington 16, D. C.

Preface

The Subcommittee on Units of Expression was authorized by the Board of Control of the Federation of Sewage and Industrial Wastes Associations on October 14, 1944. It was originally organized with Dr. Willem J. Rudolfs as Chairman. Upon his retirement in 1953, Dr. Harold E. Orford was appointed to succeed him.

The membership of the subcommittee was large because of the all-encompassing nature of the work. During the years from the organization to the production of the final report it included C. G. Anderson, H. E. Babbitt, D. E. Bloodgood, E. Boyce, L. H. Chamberlain, E. S. Chase, E. J. Cleary, M. M. Cohn, W. Donaldson, V. M. Ehlers, R. E. Eliassen, V. P. Enloe, G. M. Fair, A. P. Folwell, G. R. Frith, W. A. Hardenbergh, B. K. Hartman, W. D. Hatfield, J. K. Hoskins, C. G. Hyde, F. W. Jones,* C. E. Keefer, L. H. Kessler, T. R. Komline, L. L. Langford, C. C. Larson, R. P. Logan, F. W. Lovell, W. S. Mahlie, W. B. Marshall, F. W. Mohlman, J. A. Montgomery, G. Phelps, G. M. Ridenour, F. C. Roe, C. Ruchhoft,* T. C. Schaetzle, S. Shupe, W. A. Sperry, M. Spiegel, W. E. Stanley, G. E. Symons, M. W. Tatlock, LeRoy W. Van Kleeck, F. M. Veatch, and L. F. Warrick.

After several drafts, the subcommittee reported to the Federation Board of Control through the Sewage and Industrial Wastes Committee. Because of the controversial nature of the report, the Board of Control did not adopt it but approved publication in SEWAGE AND INDUSTRIAL WASTES as a tentative report. This report recommended that cubic feet be used in units including volume or flow. This change made possible many simplifications in the proposed units.

The report was published in the Federation Journal for February 1957 with a request for suggestions from readers. In addition, special comment was solicited from over one hundred members. With many views at hand, the subcommittee met during the Boston Federation Meeting in 1957 and decided to recommend the gallon as a unit of volume in line with common practice. The subcommittee felt this compromise best to avoid further delay in completing the report. With approval of the publication review committees, this publication of the final report was cleared.

In its final report, the subcommittee recommended:

1. That effort be continued for the adoption of a simplified standard system of units in which the unit for volume is changed from gallons to cubic feet.
2. That this work be done in conjunction with other interested societies such as the ASCE, AWWA, APHA, and ASTM.
3. That work be continued so that the recommended standard units can be revised and brought up-to-date at intervals in a manner similar to that used by the Standard Methods Committee.
4. That the recommended units of expression be used in manuscripts for technical publications.
5. That non-recommended units of expression be used in publications only where there is no comparable recommended unit.
6. That non-recommended units of expression conform, wherever possible, to the units of length, area, volume, and time used in the recommended units of expression.

The subcommittee acknowledges the many constructive suggestions received from those who commented on its previous reports. Surely the consideration this has provoked will result in improvement of our technical understandings and lead the way to further simplifications in the future.

* Deceased.

Units of Expression for Wastes and Waste Treatment

1. WASTES CHARACTERISTICS AND TREATMENT EFFICIENCY
2. SCREENINGS
3. GRIT REMOVAL
4. SEDIMENTATION
5. BIOLOGICAL FILTERS—TRICKLING FILTERS
6. BIOLOGICAL FILTERS—SAND FILTERS
7. ACTIVATED SLUDGE AND CONTACT AERATION
8. OXIDATION PONDS AND LAGOONS
9. CHLORINATION
10. DIGESTION
11. SLUDGE DEWATERING AND DRYING
12. SLUDGE DISPOSAL

For many years, engineers and technicians engaged in research, design, and operation of sewage and industrial wastes treatment plants and appurtenant facilities for the collection, pumping, and disposal of liquid wastes, have recognized the need for standard units of expression for factors used in these sanitary engineering activities. The publication of this manual of practice is in answer to this need.

The rapid advances in this field make it essential that all design and operation factors and performance units be expressed in nomenclature which is universally understandable and which permits the comparison of volume, strength, rates, time, weights, concentrations, ratios, hydraulic loading, quality characteristics, dimensions, and other pertinent factors. Uniformity will aid in the orderly development of technical practices in the sewage and industrial wastes field.

It should be noted that the following units of expression are *recommended*. The final acceptance of such units as "standard practice" must be based on voluntary acceptance and use. Therefore, this appeal is made for the use of the proposed units of expression by all persons in research, design, and operation of wastes facilities. In some instances, the units may be different from those commonly used; in other cases, they are recommended because they are already accepted and used.

For many of the units recommended, the numerical range of values usually encountered is given for each unit. These numerical values are only background figures. They have no other significance with respect to the recommendations made or the use of the units

1. WASTES CHARACTERISTICS AND TREATMENT EFFICIENCIES

1.1. Volume

Sewage and industrial wastes: gallons per day; million gallons per day.

1.2. Strength [1]

Sewage and industrial wastes: milligrams per liter.

1.3. Efficiency of Treatment [2]

Sewage and industrial wastes: percentage removal of a particular constituent (BOD, suspended solids, etc.); 100 × (influent − effluent)/(influent).

2. SCREENINGS

2.1. Volume

Cubic feet of screenings per million gallons of waste flow; range 0.5 to 12 for sewage.

3. GRIT REMOVAL

3.1. Volume

Cubic feet of grit per million gallons of waste flow; range 1 to 12 for sewage.

3.2. Surface Overflow Rate

Gallons flow per day per square foot of surface area (also state depth of grit chamber in feet); range 22,000 to 50,000 for sewage.

3.3. Displacement Velocity

Feet per second (also state length of grit chamber in feet).

3.4. Detention Time

Seconds of detention time in grit chamber (grit chamber volume basis); range 10 to 100 for sewage.

4. SEDIMENTATION

4.1. Volume of Sludge

Cubic feet of sludge per million gallons of waste flow; range 300 to 1,500 for sewage.

4.2. Weight of Dry Sludge Solids

Pounds of dry sludge solids per million gallons of waste flow; range 500 to 2,000 for sewage.

4.3. Sludge Concentration

Per cent total solids in sludge; range 1 to 10 for sewage.

4.4 Surface Overflow Rate

Gallons waste flow per day per square foot of sedimentation tank surface area; range 500 to 2,000 for sewage.

4.5 Surface-Area-Weir-Length Ratio

Square feet of tank surface per foot of weir length (ft); range 5 to 150 for sewage.

[1] Concentration of BOD, suspended solids, etc.

[2] For treatment units such as trickling filters and activated sludge tanks in which another treatment step (sedimentation) is an integral part of the process, the effluent is considered to be that from the final treatment units.

4.6 Weir Overflow Rate

Gallons waste flow per day per lineal foot of weir length; range 5,000 to 20,000 for sewage.

4.7. Detention Time

Hours detention time (settling tank volume basis); range 0.5 to 4 for sewage.

5. BIOLOGICAL FILTERS—TRICKLING FILTERS [3]

5.1. Hydraulic Load [4]

Gallons waste flow per day per square foot of surface area; low-rate filter range 25 to 100; high-rate filter range 200 to 1,000.

5.2. BOD Load [5, 6]

Pounds of BOD per day (in waste applied) per 1,000 cubic feet of filter volume; low-rate filter range 5 to 25; high-rate filter range 25 to 300.

5.3. Recirculation

Percentage recirculation: 100 × (recirculated flow/waste flow). Low-rate filter range 0 to 50; high-rate filter range 25 to 300.

Unit Replaced	*Conversion Factor* [7]	*Recommended Unit*
Million gallons per acre per day	× 23	= Gallons per day per square foot
Gallons per 1,000 square feet per day	× 0.001	= Gallons per day per square foot
Pounds BOD per acre foot per day	× 0.023	= Pounds BOD per day per 1,000 cubic feet
Pounds BOD per cubic yard per day	× 37	= Pounds BOD per day per 1,000 cubic feet

[3] Because of the large number of flow patterns possible with series operation of filters, particularly where recirculation is employed, standard expressions are not being recommended. It is recommended, however, that the same general scheme be followed for determining loadings and efficiencies of individual filters used in series as that recommended for single-stage filters in parallel. It is also recommended that for filters used in series, the over-all loadings and efficiencies be given, *i.e.*, that the two or more filters in series should be considered as one filter and the loadings and efficiencies be computed accordingly.

[4] For high-rate filters the hydraulic load includes recirculated flow.

[5] For high-rate filters, the recirculated flow is not to be considered as contributing an additional BOD load.

[6] Where high-rate filters are provided with recirculation to the primary settling tank, the recirculated flow mixes with the raw waste before primary settling. The amount of BOD contributed to the filter by the settled raw waste cannot be determined by a direct BOD measurement and must be estimated. The following are suggested methods:

1. Settle the raw waste sample in an Imhoff cone for the same detention period provided by the sedimentation tank and determine the BOD of the settled raw waste. Apply this percentage BOD reduction to the raw waste passing through the settling tank.
2. Take samples of mixed raw waste and recirculated trickling filter effluent, before and after settling, and determine the BOD concentrations. Apply the percentage BOD reduction obtained for the primary settling tank to the raw waste passing through the settling tank.
3. Assume a standard value for the percentage BOD reduction of the raw waste as it passes through the primary settling tank.

In reporting BOD loadings on this type of recirculated trickling filter, the method of estimating the BOD reduction of the raw waste portion by primary sedimentation should also be stated.

[7] Conversion factors computed using (a) density of water as 8.34 lb per gal, and (b) 7.5 gal equals 1.0 cu ft.

6. BIOLOGICAL FILTERS—SAND FILTERS

6.1. Hydraulic Load

Gallons waste flow per day per square foot of surface area; range 2 to 12 for sewage.

6.2. BOD Load

Pounds of BOD (in waste applied) per day per 1,000 square feet of surface area; range 2 to 10 for sewage.

6.3. Suspended Solids Load

Pounds of suspended solids (in waste applied) per day per 1,000 square feet of surface area; range 2 to 10 for sewage.

Unit Replaced	*Conversion Factor*	*Recommended Unit*
Gallons per acre per day	× 0.000023	= Gallons per day per square foot
Million gallons per acre per day	× 23	= Gallons per day per square foot
Gallons per 1,000 square feet per day	× 0.001	= Gallons per day per square foot
Pounds BOD per acre per day	× 0.023	= Pounds BOD per day per 1,000 square feet
Pounds suspended solids per acre per day	× 0.023	= Pounds of suspended solids per day per 1,000 square feet

7. ACTIVATED SLUDGE AND CONTACT AERATION

7.1. BOD Load

7.11. Pounds of BOD applied per day per 1,000 cubic feet of aeration tank volume; range 25 to 100 for sewage.

7.12. For activated sludge, pounds of BOD applied per day per pounds of volatile solids under aeration; range 0.1 to 1.0 for sewage.

7.13. For contact aeration, pounds of BOD applied per day per 1,000 square feet of aerator contact surface; range 3 to 30 for sewage.

7.2. Air Requirements and Measurement

7.21. Cubic feet of air per pound of BOD removed; range 300 to 1,500 for sewage.

7.22. Cubic feet of air per gallon of sewage treated; range 0.5 to 2 for sewage.

7.23. Cubic feet per minute of air flow.

7.3. Aeration Period

Hours aeration period (based on total aeration tank volume and waste flow, return sludge flow is not considered); range 2 to 24 for sewage.

7.4. Return Sludge

Per cent return sludge: 100 × (return sludge flow/waste flow); range 10 to 50 for sewage.

7.5. Sludge Index

Sludge density index [8] (see "Standard Methods," 10th Edition); range 0.2 to 2 for sewage.

Unit Replaced	*Conversion Factor*	*Recommended Unit*
Sludge volume index	(100/SVI)	= Sludge density index

8. OXIDATION PONDS AND LAGOONS

8.1. Detention Time

Days of detention time (based on lagoon volume and waste flow).

8.2. BOD Load

Pounds of BOD per day per 1,000 square feet of surface area.

9. CHLORINATION

9.1. Disinfection

9.11. Dosage: milligrams per liter of chlorine applied (for a stated contact time and chlorine residual); range 4 to 40 for sewage.

9.12. Residual: milligrams per liter of chlorine residual at contact time required to meet bacteriological standards.

9.13. Effluent quality: (a) number of coliform bacteria per milliliter remaining; (b) per cent of samples passing bacteriological standards.

9.2. BOD and Odor Reduction

Dosage: milligrams per liter of chlorine applied.

10. DIGESTION

10.1. Sludge Digestion

10.11. Pounds of volatile solids per day per 1,000 cubic feet of digester volume; range 50 to 1,000.

10.12. Days detention period (digester volume basis).

10.13. Percentage reduction of volatile solids.

10.14. Cubic feet of gas per pound of volatile solids fed.

10.2. Waste Digestion

10.21. Pounds of BOD per day per 1,000 cubic feet of digester volume; range 10 to 100.

10.22. Days detention period (digester volume basis).

10.23. Percentage BOD reduction.

10.24. Cubic feet of gas per pound of BOD fed.

Unit Replaced	*Conversion Factor*	*Recommended Unit*
Pounds volatile solids per day per cubic foot digester volume	× 1,000	= Pounds volatile solids per day per 1,000 cubic feet digester volume
Pounds BOD per day per cubic foot digester volume	× 1,000	= Pounds BOD per day per 1,000 cubic feet digester volume

[8] The sludge density index is the per cent solids in the settled activated sludge when settled under the standard conditions of the test; namely, 0.5 hr settling in 1-l graduated cylinder.

11. SLUDGE DEWATERING AND DRYING

11.1. Sand Bed Drying

11.11. Pounds of dry solids per year per square foot of bed area; range 10 to 40 for digested sewage sludge.

11.12. Feed (depth) per year wet sludge placed on drying beds; range 3 to 12 for digested sewage sludge.

11.13. Per cent dry solids in sludge cake.

11.2. Vacuum Filtration

11.21. Pounds of dry solids per hour per square foot of filter surface.

11.22. Feet per hour [9] of wet sludge applied to filter surface.

11.23. Per cent dry solids in filter cake.

11.24. Chemical dosage to dry sludge solids ratio (per cent).

11.3. Heat Drying

11.31. Btu per pound of sludge cake.

11.32. Btu required per pound of water evaporated.

11.33. Pounds of water evaporated per hour.

11.34. Per cent moisture in product.

Unit Replaced	*Conversion Factor*	*Recommended Unit*
Cubic feet wet sludge per year per square foot surface area	× 1.00	= Feet per year wet sludge on drying bed surface
Gallons wet sludge per minute per square foot of filter surface	× 8.0	= Feet (depth) per hour of wet sludge applied to filter surface

12. SLUDGE DISPOSAL

12.1. Incineration

12.11. Pounds of wet sludge per hour per square foot of heating surface (at specified sludge dry solids content).

12.12. Pounds of wet sludge per hour per cubic foot of combustion chamber (at specified sludge dry solids content).

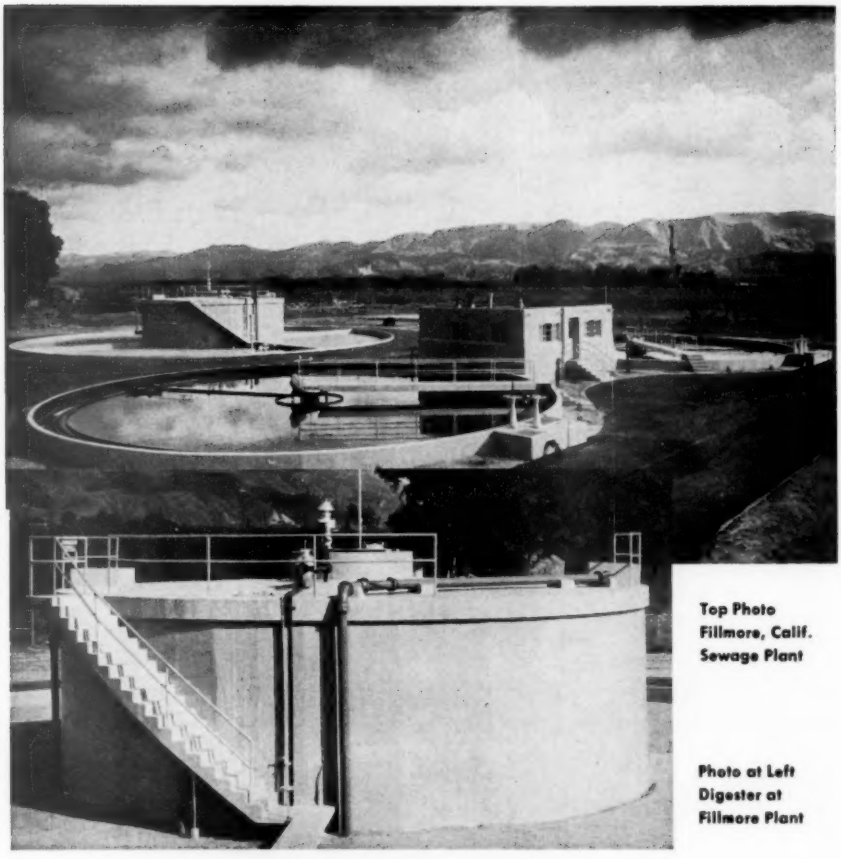
12.13. Per cent carbon dioxide in exhaust gases (by volume).

12.14. Btu per pound of moisture evaporated.

12.2. Land and Sea Disposal

Cubic feet wet solids per day, month, or year.

[9] Cubic feet of wet sludge per hour applied per square foot of surface area.



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Proceedings of Member Associations

NEBRASKA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 6th Annual Meeting of the Nebraska Sewage and Industrial Wastes Association was held November 7–8, 1957, in the Clark Hotel, Hastings, Nebr. The total number of registrants was 81 and there were 92 in attendance at the banquet.

Some of the highlights of the interesting and valuable papers which were presented were the following statements:

"The number one problem in sewage pumps is packing boxes."

"When the bearings go bad on electrical motors, always be sure to determine the cause of the bearing failure and correct it before placing the equipment back in service."

"By the Seventh Annual Meeting there will be over 200 sewage treatment plants in operation in Nebraska."

"Sewage treatment plant operators should be cautious in the use of caustic sewer cleaning chemical compounds, as they can seriously injure the operator, damage the joints, and have harmful effects on sewage treatment plants."

"No two combination clarifier plants operate the same and a set of operating standards must be developed for each plant."

"Sewage sludge is a useful fertilizer and should be used to improve agricultural soils."

(*Continued on page 200a*)

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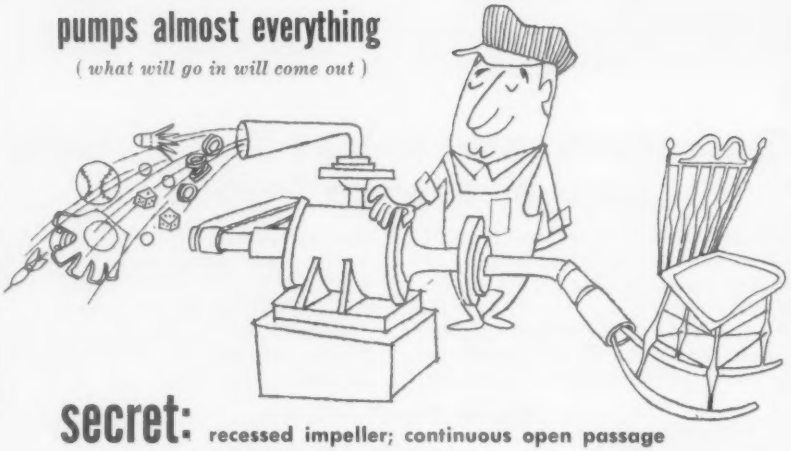

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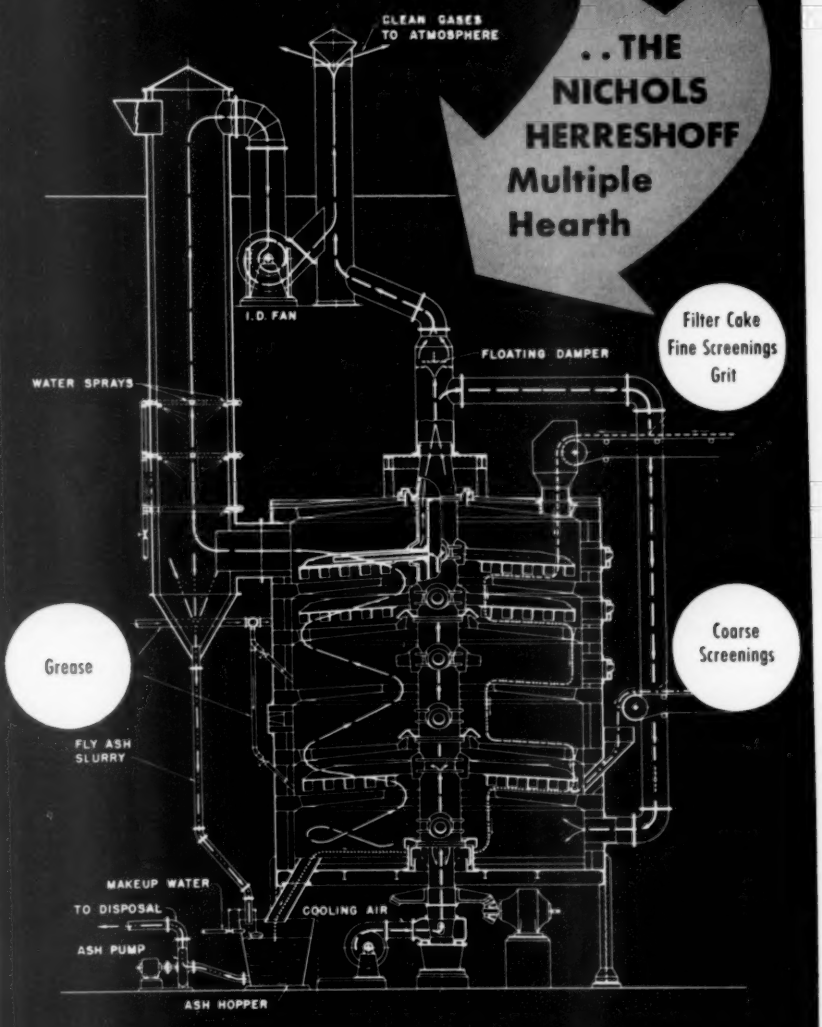

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Vice-President: Floyd Sanks, Sidney.
Secretary-Treasurer: V. J. Lechtenberg, Omaha.

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Secretary-Treasurer

PACIFIC NORTHWEST SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 24th Annual Meeting of the Pacific Northwest Sewage and Industrial Wastes Association was held at the Franklin Hotel, Seattle, Wash., October 24–26, 1957, and drew a record-breaking attendance of 275, plus 50 ladies.

General sessions were held on the morning of the 24th and afternoon of the 25th, while split sessions were held on the afternoon of the 24th and morning of the 25th. These included sessions on industrial wastes and air pollution, sewage works management, operation and maintenance, and design and development.

An operators' round table session was held on the evening of the 24th, attendance being limited to operators.

(*Continued on page 202a*)

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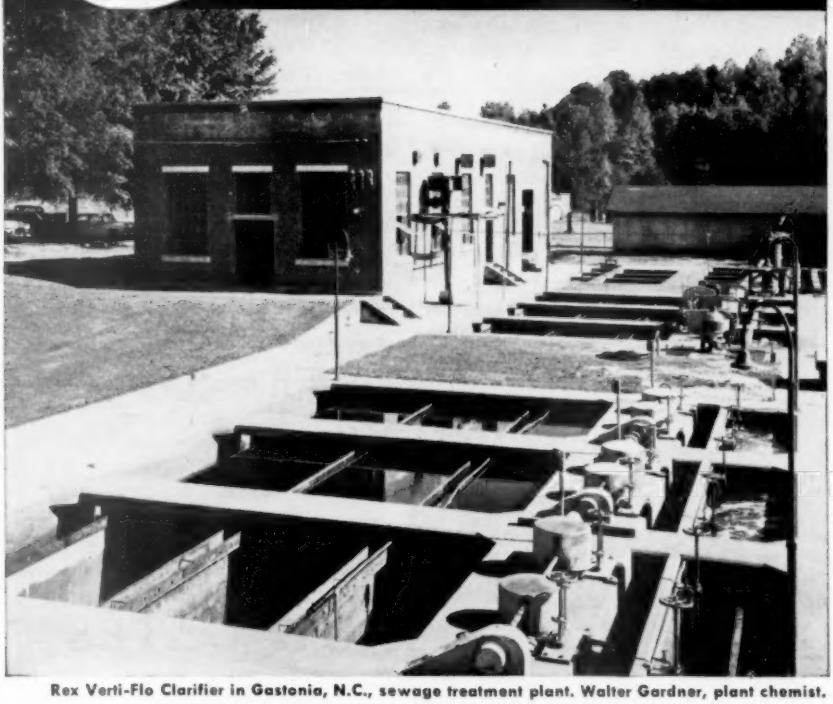

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A follow-up of this occurred at the annual breakfast the following morning.

Andrew J. Wahl, Superintendent at Boise, Idaho, and retiring president of the Association, was named 1957 recipient of the first Hatfield Award for outstanding performance in the operations field. The Bedell Award for outstanding service to the association was presented to Robert O. Sylvester, Professor of Sanitary Engineering, University of Washington, Seattle, Wash.

Ten Awards for outstanding sewage plant operation reports were made. Recipients were selected by a committee of which Robert E. Leaver, Seattle, Wash. was chairman. First place winners in each of three population groups were:

Lyman Ketcham, Tacoma, Wash., plant operator, cities over 25,000; W. E. Loftin, Gresham, Ore., cities of 5,000 to 25,000; and Vern Young of Franklin-Pierce High School, near Tacoma, Wash., facilities serving less than 5,000 population. Ketcham also won the top award last year.

Honorable mention awards in the over 25,000 group went to: A. J. Wahl, Boise, Idaho; C. S. Zickefoose, Walla Walla, Wash.; Eugene F. Davis, Seattle, Wash.; William A. Newell, Eugene, Ore.; and A. S. Wood, Vancouver, Wash. Leo Mabee, Longview, Wash.; and Wayne Ransom, Olympia, Wash., received honorable mention awards in the 5,000 to 25,000 group.

The following officers were elected to serve for 1957–58:

President: R. Trumbull Smith, Seattle, Wash.

Vice-President: Marvin W. Runyan, Portland, Ore.

Secretary-Treasurer: Gilbert H. Dunstan, Pullman, Wash.

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(Continued through page 210a)

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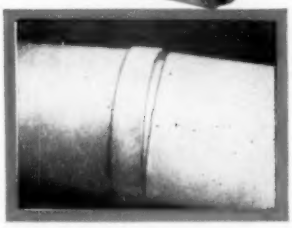

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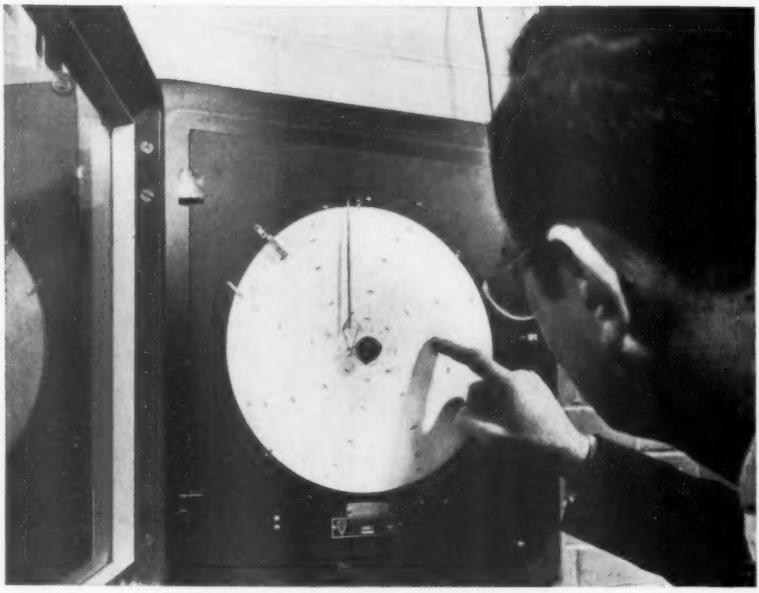

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